Modelling of EU land-use choices and environmental impacts-Scoping study. Final report and appendices

Mugdal, S.; Benito, P.; Koomen, E.

2008

Bio Intelligence Service

European Commission DG ENV

MODELLING OF EU LAND-USE CHOICES AND ENVIRONMENTAL IMPACTS – SCOPING STUDY

Contract N° 070307/2007/485312/ETU/G1

Final Report

August 2008

in collaboration with

SPIN lab
vrije Universiteit amsterdam

Bio Intelligence Service - Scaling sustainable development
Industrial Ecology - Nutritional Health

Bio Intelligence Service S.A.S - bio@biois.com
1 rue Berthelot - 94200 Ivry-sur-Seine - France
Tél. +33 (0)1 56 20 23 98 - Fax. +33 (0)1 58 46 09 95

Contact BIO Intelligence Service
Shailendra Mudgal – Patricia Benito
☏ + 33 (0) 1 56 20 28 98
shailendra.mudgal@biois.com
patricia.benito@biois.com

Project Team

- **BIO Intelligence Service (Team Leader)**
  Mr. Shailendra Mudgal
  Ms. Patricia Benito

- **SPINLAB, Vrije Universiteit, Amsterdam**
  Mr. Eric Koomen

DISCLAIMER

This report contains the results of the research conducted by the project consortium and should not be perceived as the opinion of the European Commission.

Contents

1. Executive summary 5

2. Introduction 11

3. Background and objectives 13

3.1. Background 13
3.2. Objectives of this study 13
3.3. General approach 14

4. Theory of land-use choices 15

4.1. Land use or land cover 15
4.2. Application of the DPSIR framework to land-use change 16
4.2.1. Driving forces 16
4.2.2. Pressures 18
4.2.3. State and trends in land-use change 19
4.2.4. Socio-economic and environmental impacts 22
4.2.5. Policy responses 24
4.2.5.1 Overview of policy responses 24
4.2.5.2 Key EU policies related to land-use choices 26
4.2.5.3 Trade-offs while minimising environmental impacts 32

5. Identification of relevant projects/models 35

5.1. Application of land-use models in policy making 35
5.1.1.1 Application of land-use models in the Netherlands 36
5.1.1.2 Application of land-use models at EU level 37
5.2. An EU modelling framework for impact assessment 39
5.2.1. Pre-processing phase 41
5.2.2. Core modelling system 41
5.2.3. Post-processing phase 43
5.2.4. Policy support system 44
5.3. Relevant research projects 44
5.3.1. Pre-processing phase 44
5.3.2. Core modelling system 45
5.3.3. Post-processing phase 55
5.3.4. Policy support system 59

6. Comparing existing models 61

6.1. Relevancy 61
6.1.1. Simulation of multiple land-use changes 61
6.1.2. Spatial resolution 61
6.1.3. Simulation at multiple scales 61
6.1.4. Applicability for decision making 62
6.1.5. Time horizon 63
6.1.6. Assessment of environmental, social and economic impacts 63

6.2. Model use ... 64
6.2.1. Expertise required, model utilisation, and Interpretation of results ... 64
6.2.2. Simulation time ... 65
6.2.3. Linkage potential ... 65
6.3. Technical requirements ... 65
6.4. General remarks ... 65
7. Options for a possible land-use policy model ... 67
7.1. Foreseen applications ... 67
7.2. Model structure ... 74
7.2.1. Basic architecture ... 74
7.2.2. Usability ... 76
7.3. Operational issues ... 76
8. Roadmap for further development ... 77
8.1. Foreseen applications ... 77
8.1.1. Application domain ... 77
8.1.2. Application type ... 78
8.2. Model Structure ... 78
8.2.1. Basic architecture ... 78
8.3. Operational issues ... 80
8.3.1. Land-Use model input ... 80
8.3.2. Land-use model output ... 80
8.3.3. model characteristics ... 81
8.4. Resource estimation ... 82
9. Conclusions ... 85
10. References ... 87

1. EXECUTIVE SUMMARY

Background

There are often conflicts between the need for land for a particular use and the capacity of land to absorb and support this need. Policy is one of the key drivers influencing the land-use change but it is also one of the responses of society to observed negative land-use patterns. Therefore, understanding the links between land-use choices and their potential impacts and the quantification of these impacts is crucial for the development of sustainable policies. In this context, simulations of land-use changes and their potential consequences can provide most useful information in studies related to the preparation, development and evaluation of large-scale spatial plans and strategies. Different tools exist, but no integrated model or suite of models still allows for a proper assessment of the environmental impacts of land use choices. Furthermore, the integration of environmental impacts of land-use changes is not sufficient to help policy makers in making a choice between different policy options from environmental perspective.

Objectives and Methodology

In this context, this study had the objective to define the scope of a future integrated assessment modelling framework1 that would be able to address different issues related to land-use changes in Europe, in particular related to the environmental impacts of land-use changes. The study essentially conducted a review of existing modelling tools and their applicability potential for the needs of the European Commission (more specifically DG Environment). This report can serve as a reference document for future work on this issue whether internally at the Commission or for future developers of the modelling framework.

The study overviews first the different land-use choices, the possible trade-offs, and the environmental impacts caused by land-use changes. To this end, the Drivers–Pressures–State–Impacts–Responses (DPSIR) framework is used to discuss the state and causal factors related to changes in land use in Europe as well as the possible policy responses to observed negative land-use patterns.

Based on literature review and a number of interviews with land-use modellers in Europe, the study presents some of the most relevant modelling tools, mainly developed in Europe, and analyses the existing gaps and overlaps, and their usefulness for policy making. Options for a quantitative modelling framework at the EU level are

1 The term « framework » is used here in a generic manner and should not be looked upon as the technical terminology which essentially contains a whole set of models. The focus here is to judge the suitability of existing tools in this domain and this « framework » could be a superset/subset of these tools.

introduced and compared. A roadmap for a development of such modelling framework is proposed as well as future research work necessary to address the identified gaps. The proposed roadmap was discussed with experts and Commission representatives during a workshop in Brussels on 26 June 2008.

- Land-use changes and the application of modelling tools for sustainable policy making

Driving forces (e.g. economy growth, demographic dynamics, etc) affect land use in the form of direct or indirect specific pressures, which are the stresses that human activities place on land use. For example, urbanisation, which is driven by demographic dynamics, i.e. migration, is now considered as the most significant process of land-use change in Europe. Indeed, the Corine Land-cover database shows significant changes in land use in Europe. Between 1990 and 2000, at least 2.8% of the Europe's land was subjected to a change in use, including a significant increase in urban areas. Big differences exist across MS and regions, with the proportion of the surface sealed ranging from 0.3% to 10%. Changes in habitat, water and air quality, and the quality of life are some of the environmental, social, and economic concerns associated with land-use and land-cover changes. These impacts can be direct, such as the destruction of natural habitats and landscapes, or indirect, such as increase in the amount of road traffic leading to more congestion, air pollution and greenhouse gases.

Today's society faces the challenge of reducing the negative environmental impacts of land-use practices while maintaining socio-economic benefits. Therefore, comparing land use and trade-offs of ecosystem services and assessing inherent trade-offs between meeting human needs and maintaining the capacity of ecosystems to provide goods and services will be crucial for the future land-use management. Policies can promote sustainable land-use practices by taking into consideration the different possible trade-offs and reconciling conflicting objectives. This complex task requires precise information on current developments, insight in possible future trends, the preparation of alternative policy measures, and an understanding of the impacts. In this regard, land use modelling tools can be used to assess to what extent full implementation of these instruments may achieve adequate protection or strengthening of land services. Land-use modelling frameworks apply a wide range of indicators and additional modelling tools to assess potential impacts of simulated changes in land use. Functional indicators should relate to specific policy themes (e.g. the results are to be provided at the appropriate scale), be intuitively understandable for policymakers, capture the essence of simulation results and discriminate between different simulation outcomes.

At MS level, the Netherlands has considerable experience in the application of land-use modelling tools in policy making (e.g. Environmental Outlooks, ex-ante evaluation National Spatial Policy Plan and Sustainability Outlook 1 and 2). At EU level, different modelling relevant tools that integrate land-use changes modelling have been developed recently. European institutions such as the Commission, the Joint Research

Centre (JRC) and the European Environmental Agency (EEA) have supported and collaborated in the development of this type of tools. Nevertheless, their application in policy-making at the European scale is still very limited.

- Conceptual structure of existing modelling frameworks

From a conceptual point of view, the main components of a modelling framework in the context of ex-ante impact assessments can be divided in several phases: pre-processing, the core modelling system (to predict the impacts caused by land-use changes), post-processing (presentations of output results in different formats), and a policy support system (PSS) to allow policy makers and other interested parties to simulate easily policy scenarios and their environmental, social, and economical impacts. The core modelling system of a modelling framework can be constituted by different types of components, which will be selected according to the specific policy questions that are addressed and the potential impacts analysed. A complex modelling tool, understood here as a whole set of models, can include sectoral models (to estimate the regional demands and restrictions for land-use change for different sectors ,such as CAPRI, EFISCEN or ASTRA), global models (to provide information on global demand and supply, such as NEMESIS or LEITAP) and land-use allocation models (to define potential land use changes in the future taking into account the demands from different sectors, such as CLUE-s, the Land Use Scanner or Metronamica). The different models are linked by means of an interface or software infrastructure that is going to allow different feedbacks between them.

Many of the land-use modelling environments are equipped with specific indicators or coupled with additional modelling tools. From a modelling perspective, different types of indicators can be distinguished depending on the type of information that is used for their estimation and their level of aggregation: land-use based indicator (which are use to characterise changes in land use), enhanced land-use indicator (which relies on additional data from other external sources and contribute to evaluate more complex issues, such as, for example, flood risk), and indicator-model coupling that combines land-use simulation results with additional spatial models to analyse complex issues such as biodiversity, accessibility, and possible water shortages impacts.

- Gaps and limitations of existing modelling tools

Most of the existing land-use modelling tools have mainly focused on either the biophysical, economic or social disciplines and in general, the degree of quantification of the potential environmental impacts of land-use changes is not balanced. A crucial remaining challenge is to develop multi-scale methods that allow improving and performing analysis at micro and macro scales and that acknowledges that different driving forces are important at different scales. In this regard, one of the main barriers is to obtain data on specific regional economy and policies, which would be useful to establish land claims allocation between different sectors at the regional or local level. Most modelling frameworks and modelling tools use a top down approach.

In general, social aspects and drivers such as quality of life, formal and informal social rules, and people's preferences and behaviour (which can have a very relevant influence on land-use changes particularly at the local and regional levels) are generally not well represented in most modelling tools.

Many modelling tools are case specific, which limits their re-utilisation in policy questions other than the ones addressed originally and their timely availability for application to rising policy issues. Moreover, different components of existing modelling tools are rarely re-usable outside the environment for which they were developed.

No single existing model is capable of assessing all the potential environmental, economic and social impacts of land use choices that might be of relevance for the Commission at the appropriate scale and therefore, coupling different components is usually required for the assessment of complex issues. To date, many land-use modelling frameworks rely on separate impact models to analyse more complex themes but most still do not offer a full integration of the relations that exist between different impacts and the feedbacks that might occur between specific impacts and the use of land. In this regard, one of the main difficulties is the linkage of the different components or models.

- Requirements for an EU modelling framework for impact assessment

For a land-use model to be relevant and of value for EU policy-making or support, it must be able to model and project outcomes for scenarios that relate to the EU needs. The modelling framework should allow simulating different types of land-use changes simultaneously. Overall, a relevant land-use modelling tool has to support the policy needs of different DGs of the European Commission such as ex-ante assessment and impact assessments. Such framework should be able to estimate the economic, environmental and social impacts of land-use across a range of scales (from EU-27) to MS and regional level) while taking into account global sources driving forces such as demography, economic growth or climate change. The modelling framework should focus on a broad understanding of cross-cutting trade-offs of sector impacts and be flexible to allow taking into consideration new policy developments.

- Options for a possible EU land-use policy modelling framework

From the 'application' perspective, a model can be sector specific (e.g. agriculture, urban sprawl, transport) or integrated (e.g. addressing cross-cutting issue such as climate change affecting all types of land use and different sectors), and its results can be used during different phases of the policy-making process (i.e. preparation, development and evaluation of large-scale spatial plans and strategies). From an architectural point of view, models can be developed as stand-alone entities that replace existing components (such as in the SEAMLESS framework) or as integration framework that use existing components (such as in the Eururalis framework). Depending on the architecture, the modelling tool will be more or less user-friendly or a specialist's tool (demanding, but flexible). From the operational perspective, land-use model output is typically delivered in the form of tables and maps, but in order to provide sensible results for policymaker, additional impact assessment tools may be applied.

- Roadmap for developing a future EU modelling framework

An integrated application seems be most suitable for the current and foreseen Commission's analytical needs. This approach requires, however, complex linkages between (sub-) domains and using sector-specific models (likely: hydrology, climate, tourism, agriculture, forestry, economics, and transport) that can simulate different types of land use.

The main application type of the modelling tool to be developed will be ex-ante policy assessment and planning during the development phase, and it will include many different types of scenarios and spatially explicit policy options. In this regard, it is important to highlight that a potential failure for a modelling framework is a mismatch between the modelling and the policy context. The modelling should be tailored to the policy options that are defined and the output (in the form of indicators/information) it needs to produce for the evaluation.

For the basic modelling architecture, the use of a component-based model seems to be most appropriate; with different sector-specific models (representing different processes at different hierarchical levels) constituting discrete and reusable components that could be integrated in the modelling framework depending of the policy questions to be addressed. The models to be used should have been validated previously and with concrete application in real cases and therefore, it is advisable to use, and adapt if necessary, existing modelling tools. Indeed, the future EU modelling framework should take into account previous relevant modelling experiences gained through different EU projects such as Eururalis, SENSOR, NITRO-EUROPE, FARO, EFORWOOD, PLUREL and RUFUS projects, and specific tools developed in these projects.

The future modelling framework will have to be run by trained modellers given the complexity of the expertise required to integrate and calibrate the different components of the model (specialist's tools). In spite of this, an active involvement of policy makers is crucial along the whole process of development of the modelling framework.

Further awareness rising among policy-makers and also scientist is necessary about the current state of modelling tools, their potential, policy analytical needs, and the needed development.

This page is left intentionally blank.

2. INTRODUCTION

This is the final report of the scoping study on modelling of EU land-use choices and environmental impacts commissioned by DG Environment.

This study had the objective to define the scope of a future integrated assessment modelling framework[2] that would be able to address different issues related to land-use changes in Europe, in particular related to the environmental impacts of land-use changes. As the work progressed, the study evolved in the form of a review of existing modelling tools and their applicability potential in this context. This report can serve as a reference document for future work on this issue whether internally at the Commission or for future developers of the modelling framework.

The study compiles information about some of the most relevant modelling tools, mainly developed in Europe, and analyse the existing gaps and overlaps, and their usefulness for policy making. There are a large number of existing modelling tools, but we have mainly focused the research on those that seemed to be more relevant for the future modelling framework and to illustrating the range of available tools. The different modelling tools are presented and discussed in the context of a proposed general modelling framework structure. Various comparative tables are prepared for this purpose and presented in the main body or the Appendices.

Finally, possible solutions for the future development of a modelling tool for the European Commission are presented and compared. A roadmap for a development of such modelling framework is proposed as well as future research work necessary to address the identified gaps. The proposed roadmap was discussed with experts and Commission representatives during a workshop in Brussels on 26 June 2008. Overall, it seems important to understand first the policy questions to be addressed and to integrate the necessary different components than to develop a one-size-fits all modelling tool. There are models and modelling tools already available that can fit into some of the blocks, but still some further research is required to facilitate the process and face eventually the identified limitations.

[2] The term « framework » is used here in a generic manner and should not be looked upon as the technical terminology which essentially contains a whole set of models. The focus here is to judge the suitability of existing tools in this domain and this « framework » could be a superset/subset of these tools.

This page is left intentionally blank.

3. BACKGROUND AND OBJECTIVES

3.1. BACKGROUND

Changes in land use have been essential for humanity since they have enabled humans to meet their needs in terms of critical ecosystem services such as food, freshwater, and shelter. While the demand for such services continues to rise with growing human population and wealth, there is a potential risk that the resulting environmental impacts of land-cover modifications could finally reduce the very capacity of the biosphere to provide goods and services in the long run.

The understanding of the links between land-use choices and their potential impact on the environment as well as the quantification of these impacts is crucial for the development of policies in order to minimise them (Constanza and Voinov, 2003). In most of the countries, land-use planning and management decisions are usually made at local, regional, or national levels. However, the European Commission plays a key role by defining policies to improve the sustainability of the European Union (EU) as a whole. Such policies, when transposed by the Member States (MS), enable them to integrate EU-wide sustainability concerns and priorities when developing their national or sub-national land-use development plans.

Most of the impacts related to land-use changes show up a long time after the changes have been made, thus simulation models are often very useful to have a vision of possible impacts beforehand. Such models facilitate the understanding of the interaction of complex processes and thus help make projections for possible future land-use configurations. Therefore, they can support the analysis of the causes and effects of land-use change. The use of such models can be extremely helpful for the formulation of adequate land-use policies and this has already been practised in many countries e.g. the Netherlands.

3.2. OBJECTIVES OF THIS STUDY

Initially, this study had the objective to define the scope of a future integrated assessment modelling framework that would be able to address different issues related to land-use changes in Europe, in particular related to the environmental impacts of land-use changes. As the nature of these impacts is often irreversible and such impacts may only become visible a long time after the land-use changes have been made, it can be useful to have an intelligent modelling tool which would be able to provide a reasonable prediction of future scenarios and will provide the means to the policy makers to analyse different land-use options on the basis of which a policy decision can be based.

As the work progressed, the study evolved in the form of a review of existing modelling tools and their applicability potential in this context. This report can thus serve as a reference document for future work on this issue whether internally at the Commission or for future developers of the modelling framework.

The present study also aims at presenting and comparing the different options that are possible for a future land modelling framework useful for the European Commission. On the basis of the analysis of possible options, a roadmap for a development of such modelling framework is also proposed.

Before discussing different options for a potential land-use modelling tool, this study analyses the concepts of land-use change and related environmental impacts and also analyses the trade-offs in a wider context of the EU policy. Furthermore, existing models and tools are reviewed in order to see whether existing tools (or a combination of models) can be adapted to the needs of the European Commission.

3.3. GENERAL APPROACH

This study involves the analysis of possible interactions of the EU environmental policy with other relevant policies at the EU, MS, or regional/local levels that may affect the land-use management, whether directly or indirectly. The key elements to be analysed are following:

- Overview of the land-use management practices and the environmental impacts caused by land-use changes.
- Identification of critical issues arising because of discrepancies among different land-use management approaches.
- Analysis of the scope of different land-use modelling research programs, existing gaps and overlaps, and their usefulness in a broader policy context.
- Options for a quantitative modelling at the EU level and the assessment of the strengths and weaknesses of each of the options.
- Presentation of these options at a stakeholder workshop in the presence of key experts and adoption of most suitable option(s).
- Definition of a roadmap for an integrated modelling framework based on the selected option(s).

The workshop support material (i.e. presentations and list of participants) is provided in Appendices 1 and 2. The outcomes of the workshop were summarised in the minutes that are presented in Appendix 3. The appendices are included in a separate document.

4. THEORY OF LAND-USE CHOICES

4.1. LAND USE OR LAND COVER

Land use is the most clearly visible result of human interaction with the biophysical environment and in all but the most inhospitable and remote mountain ranges, deserts, and forests man has altered the pristine landscape through various types of use (Koomen et al., 2008a). In fact, land is a limited resource and the need for resources and space and the capacity of the land to absorb and support this need can thus lead to conflicts. Land-use change can thus be considered as a key factor in the development of the human and physical environment.

Land can simultaneously be used for different purposes (for example, agriculture and recreation) and locally can have different main uses related to the same cover (for example nature reserve and wood production). Many authors, therefore, explicitly distinguish between *land cover* and *land use* (e.g. Lambin et al., 2001). *Land use* refers to how land is used by humans and entails the economic uses of land such as domestic (household or residential), commercial, industrial, recreational, and agricultural. *Land-cover*, on the other hand, refers to the vegetation, structures, or other features that cover the land.

In general, the following land uses can be identified:

- Farming and food production
- Forestry
- Nature conservation
- Transport infrastructure
- Energy production
- Recreation and tourism
- Housing
- Industry and trade
- Commerce
- Mining and quarrying
- Waste dumping
- Water management

The land-use and land-cover classifications used by existing relevant models and databases are included in Appendix 4. It can be observed that in many cases, land use and land cover are used interchangeably and the level of detail of classification also varies considerably.

4.2. APPLICATION OF THE DPSIR FRAMEWORK TO LAND-USE CHANGE

The Drivers–Pressures–State–Impacts–Responses (DPSIR) framework is used in the following sub-sections to discuss the state and causal factors related to changes in land use in Europe. Driving forces of land-use change are discussed in sub-section 4.2.1. Some of the pressures resulting in land-use changes and their relation with the main driving forces are briefly described in sub-section 4.2.2. The current state of land use in Europe and the observed dynamics in response to the drives and resulting pressures are presented in sub-section 4.2.3. The environmental, social and economic impacts associated with land-use and land-cover changes are summarised in sub-section 4.2.4. Finally, sub-section 4.2.5 briefly describes how society faces the challenge of reducing the negative environmental impacts of land-use practices through policy response.

4.2.1. DRIVING FORCES

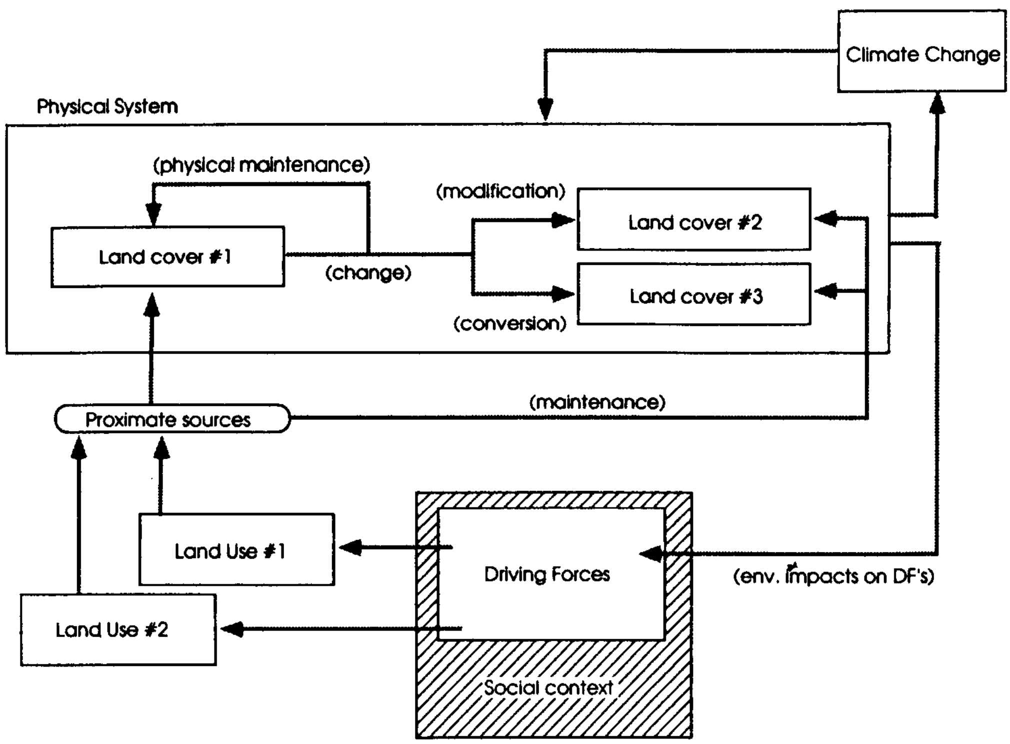
Several studies have examined the social and economic factors that drive land-use and land-cover change (Turner et al., 1993; GLP, 2005; Hersperger and Bürgi, 2007). These studies identify the following main drivers for land-use changes:

1. **Demography:** An increase in population results in an increased demand for housing and other facilities, such as offices, shops, and public infrastructure. Similarly, a declining population reduces the need for constructing new housing and infrastructure. The increase in ageing population also results in a growing number of households, though with fewer members.
2. **Economy:** A booming economy results in construction of new commercial and industrial buildings. Further, economic growth creates new jobs and thus attracts more workers, leading to population growth, and construction of new houses and infrastructure. With a rise in incomes, people often choose to build larger houses, leaving smaller, older houses vacant.
   A change in the price of agricultural or forest products can, furthermore, affect landowners' decisions to keep land in those uses. Also, policies aimed at supporting agricultural prices provide an incentive to keep land in farming.
3. **Society:** Changes in the attitudes and values of people have considerable impact on land-use patterns. Average household size in the EU, for example, has been decreasing over time (from 2.8 in the 1980 to 2.4 in 1996). Therefore, reducing household sizes necessitates more housing units to accommodate same number of people.
4. **Politics:** National, regional, and local planning and policies influence greatly the rate at which land-use and land-cover changes. Spatial planning typically aims to ensure that spatial goals are achieved in the future.

5. **Technology:** Technological developments influence the intensity of activities e.g. agricultural mechanisation, improvements in methods of converting biomass into energy, use of information-processing technologies in crop and pest management, and the development of new plant and animal strains through research in biotechnology. Such developments often alter the usefulness and demand for different types of lands. Extension of basic transport infrastructure such as roads, railways, and airports, can further take up land resources and result in their overexploitation and degradation.

To understand the land-cover change as an element of global environmental change, it is important to specify the links between the human elements generating changes both in land use and in the physical systems that are affected by the resulting changes in land-covers. Figure 1 presents the basic states, processes, and involved flows in a simplified manner (Turner et al., 1993).

Figure 1 - Linkages among driving forces and changes in land use and cover



In this schema, a land-cover (physical system) exists in a systemic relationship with human uses (land use) and the causes of those uses. Driving forces interact among themselves and lead to different land uses depending on the social context in which they operate. At time t, the underlying human driving forces lead to actions precipitating demand for land use #1, which requires the manipulation of the land-cover by means of technology employed in human activities such as clearing, harvesting, or adding nutrients (proximate sources of change). This manipulation is directed either to changing the existing land-cover (#I to #2 or #3) or to maintaining a particular cover (#1). In the former, the existing cover is changed to a new state that must be maintained in the face of natural processes that would alter it (physical maintenance loop).

Changes to a new state of land-cover are of at least two kinds: modification as in land-cover #2 (e.g. fertilisation of cropland or planting exotic grasses in pastures) and conversion as in land-cover #3 (e.g., forest to cropland or dry land to paddy agriculture). Maintenance processes sustain the land-cover conversion (#3) or modification (#2). Therefore, proximate sources can be seen as those of conversion, modification, or maintenance. The environmental consequences of the uses of land-cover (changes in the state of cover) affect the original driving forces through the environmental impacts feedback loop. Likewise these land-cover changes (#2 and #3) can be repeated elsewhere such that they reach a global magnitude that triggers climate change, which in turn feeds back the local physical system, affecting land-cover and ultimately the driving forces through the environmental impact loop. Regardless of the cause - local or global environmental impacts or the interaction of the driving forces in their social context - changes in driving forces at time t2 may trigger a new land use (#2), with new consequences for the land-use/cover system. This perspective indicates that understanding of global environmental change must consider the conditions and changes in land-cover engendered by changes in land use; the rates of change in the conversion-modification-maintenance processes of use; and the human forces and societal conditions that influence the kinds and rates of the processes (Turner et al., 1993).

Usually, it is a combination of synergetic drivers rather than single drivers that lead to land-use changes. For example, it has been observed that in the case of tropical deforestation, economic factors are responsible for it in 81% of the cases. Commercialisation and the growth of mainly timber markets as well as market failures are frequently reported to drive deforestation (De Sherbinin et al., 2002).

- Driving forces considered in existing models and databases

The driving forces considered in existing models vary, but in general, economic growth, population dynamics, and policy interventions are the commonly used ones. The driving forces considered in some existing models and databases are presented in Appendix 5.

4.2.2. Pressures

Driving forces (e.g. economy growth, demographic dynamics, etc) affect land use in the form of direct or indirect specific pressures, which are the stresses that human activities place on land use.

A key aspect of demographic dynamics is human migration, including shifts to and from rural and urban areas. Urban areas continue to draw labour from rural agricultural areas, thus increasing urban population. Urbanisation is now considered as the most significant process of land-use change in Europe. Historically, the growth of cities was fundamentally linked to increasing population. But nowadays, urban sprawl is no longer tied to population only but also to other factors such as individual housing preferences, commercial investment decisions, and the coherence and effectiveness of land-use policies at all levels (EC, 2007). The most obvious signs of this urban development are the spread of built-up areas, and the creation of large transport networks, but the establishment of recreational facilities such as theme parks and golf courses and the conversion of farmsteads into residences and hobby farms in near-urban landscapes are also very visible markers of this drift to urbanisation. This urban sprawling results in increased energy, land, and soil consumption. At the same time, sprawl has accelerated in response to improved transportation links and enhanced personal mobility.

This urbanisation processes has also resulted in a decline of the share of agriculture areas. Urbanisation is spreading into rural areas around the metropolitan centres where in-migration is occurring (EC, 2007). In addition, agricultural land abandonment is taking place in more marginal European regions, especially concerning extensively farmed areas that often have a high agricultural biodiversity (EC, 2006). Another example of pressure inducing land-use change resulting from economy growth is waste. As European society has grown wealthier, it has created more and more waste. Each year about 1.3 billion tonnes of waste is generated in the European Union and about 40 million tonnes of it being hazardous. As most of the waste is either burnt in incinerators or dumped into landfill sites (67%), the land dedicated to waste landfills has increased. Landfilling not only takes up more and more valuable land space, it also causes air, water, and soil pollution.

4.2.3. STATE AND TRENDS IN LAND-USE CHANGE

As indicated earlier, different models and modelling frameworks have been developed to simulate possible land-use changes over time in a consistent and systematic way. The land-use patterns that are described hereafter are taken from some of these models of land-use change and related studies.

The Corine Land-cover database[3] shows significant changes in land use in Europe. Between 1990 and 2000, at least 2.8% of the Europe's land was subjected to a change in use, including a significant increase in urban areas. Big differences exist across MS and regions, with the proportion of the surface sealed ranging from 0.3% to 10%.

- Urban areas

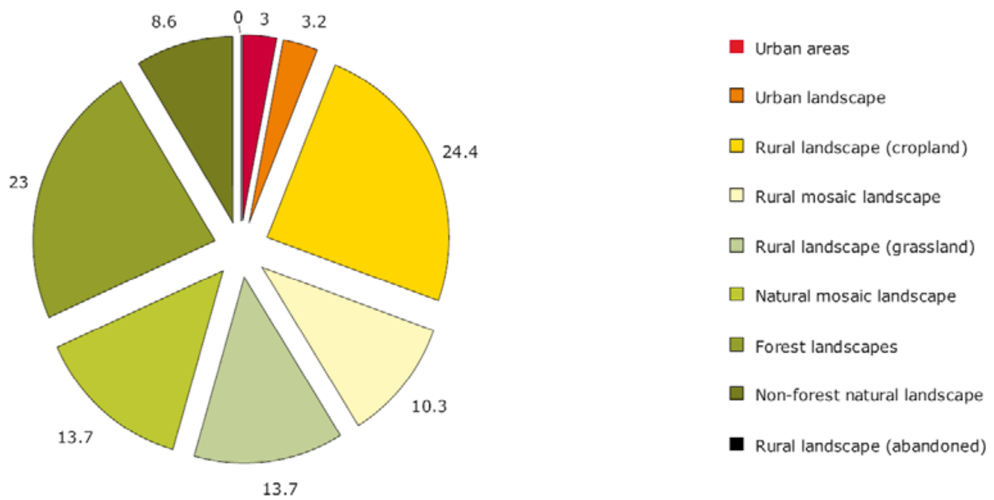
More than a quarter of the European Union's territory has now been directly affected by the urban land use and it has been estimated that by 2020, approximately 80% of

[3] http://terrestrial.eionet.europa.eu/CLC2006/

Europeans will be living in urban areas (EEA, 2007). The areas with the most visible impacts of urban sprawl are in countries or regions with high population density and economic activity (e.g. Belgium, Netherlands, south and west Germany, north Italy, and the greater Paris region) and/or with rapid economic growth (e.g. Ireland, Portugal, east Germany, and the Madrid region). Hot spots of urban sprawl are also common along already highly populated coastal strips. Since the mid‑1950s, European cities have expanded on average by 78%, whereas the population has grown by only 33%. A major consequence of this trend is that European cities have become less and less compact. During 1990–2000, the growth of urban areas and associated infrastructure throughout Europe consumed more than 8,000 km^2 of land (a 5.4% increase), which is equivalent to the entire territory of Luxembourg.

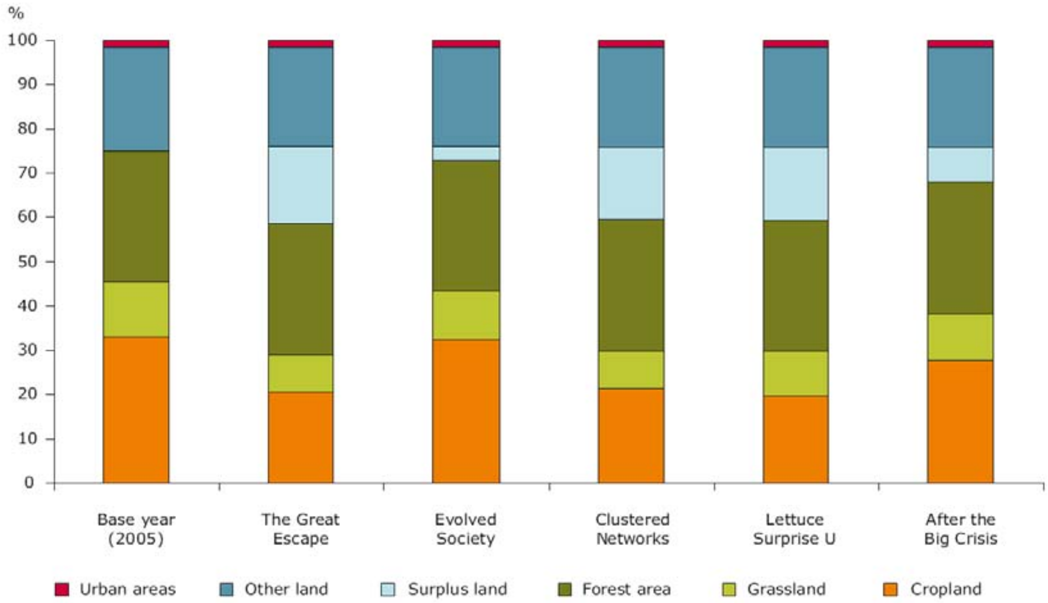
The PRELUDE project of the European Environment Agency (EEA)[4] aimed at developing coherent scenarios to describe plausible future developments for land use in the EU-25[5] plus Norway and Switzerland for the period 2005–2035. Figure 2 shows the composition of the European landscape in the base-year 2005 according to the typology of the model used for this project. Figure 3 summarises the relative changes in major land cover types between 2005 and 2035 for the EU-25 for all the five scenarios. According to the results, the highest urban changes are expected for the scenarios with migration between different European regions, but in general, the overall share of urban land use does not change much in any scenario compared to the base-year (2005). This is also in line with the results of the EC study "Scenar 2020 – Scenario study on agriculture and the rural world", that showed an increase of 1% for urban areas by 2020 (EC, 2007).

Figure 2 -Allocation of the EU landscape types in 2005 in PRELUDE (EEA, 2007)



[4] http://scenarios.ew.eea.europa.eu/reports/fol077184
[5] It has been planned to be extended to EU-27

Figure 3 - Projected land cover types in 2035 for five scenarios compared to the baseline scenario (2005) as estimated by the PRELUDE project (EEA, 2007)



- Rural areas

According to the previously mentioned EC Scenar 2020 study (EC, 2007), the land use in rural areas is changing rapidly. During the period 2000-2020, arable land is expected to decrease by 5% and grasslands and permanent crops by 1% each. On the other hand, recently abandoned land will increase in land-cover by about 3%. The individual regional changes in land-cover are expected to be between 4-10% of their territory. The results of the study also suggest that in most areas where agricultural land use is decreasing, forestry is increasing and there are also some regions in which both these land uses are declining. Other important results of this study are:

- For cereals, in spite of the expected increase in production, land requirements will decrease because of technical productivity improvements.
- Livestock will concentrate on dairy, poultry meat, and pork meat production.
- Due to the promotion of biofuels, the area devoted to oilseeds will increase.

The results of the PRELUDE project suggest that agricultural land use decreases in all scenarios. While in 2005, rural areas (particularly the cropland-dominated ones) represent the major landscape type in Europe; in 2035 this is true for only one of the analysed scenarios.

- Forest areas (including protected areas)

According to the UNECE and FAO study "European Forest Sector Outlook Study 1960-2000-2020" which involved the development of models and simulations for the future, long-term trends in forest resources have been generally stable in Europe. According to the results of this study, the forest area has consistently increased over recent decades. This expansion of the forest resource can be observed both at the European and sub-regional level (and also in most countries). The total area of forest and other wooded land has increased by 3% since 1980 (until 2005) and the area of forest available for wood supply has similarly expanded in most countries. Total forest area in Europe is expected to increase by around 5% between 2000 and 2020. This is expected due to a mixture of afforestation and natural processes and to occur both on former agricultural land as well as along the tree margins in mountain and boreal areas. However, the area available for wood supply might decrease, due to increasing demands to set-aside forests for other functions such as biodiversity conservation, recreation, and protective functions (UNECE and FAO, 2005). On the other hand, results of the EC Scenar 2020 study suggest that forests will increase in land-cover by 1% by 2020 and the land-cover other natural vegetation will also increase by 2%. The PRELUDE project suggest also a slight increase in forest areas for all the scenarios until 2035, as the results are based mainly on the current low trends of afforestation.

4.2.4. Socio-economic and environmental impacts

Changes in habitat, water and air quality, and the quality of life are some of the environmental, social, and economic concerns associated with land-use and land-cover changes. These impacts can be direct, such as the destruction of natural habitats and landscapes, or indirect, such as increase in the amount of road traffic leading to more congestion, air pollution and greenhouse gases. The large-scale deforestation and subsequent transformation of agricultural land in tropical areas are examples of land-use changes with strong impacts on biodiversity, soil degradation, and material resources to support human needs (Lambin et al., 2003). Land-use change is also one of the relevant factors among the determinants of climate change and the relationship between the two is interdependent i.e. changes in land use may impact the climate whilst climatic change will also influence opportunities for future land use (Dale et al. 1997; Watson et al., 2000). According to the Millennium Ecosystem Assessment[6], the main driver of ecological modifications and biodiversity loss at the global scale are the long-term human-induced changes in land use.

Following are main resources affected by land-use changes:

- **Habitat**: Land use by human leads to changes in land-cover that can negatively impact biodiversity, e.g. conversion of natural wood- and grass-lands to more developed uses decreases the amount of available habitat. The pattern of human land use also tends to result in a patchy landscape, fragmenting habitats. Some species of plants and animals do better in patchy, fragmented environments, while others need large, uninterrupted areas.

[6] http://www.millenniumassessment.org/

- **Water quality and quantity**: Changes in land use can affect the volume, timing, and quality of water. In particular, changes in the urban surface, forest cover and agricultural use can have an important influence on the hydrological cycle causing water shortages and floods (Dekkers and Koomen, 2007; Van der Hoeven et al., 2008). More developed land uses have higher proportions of impervious surface (areas where water cannot permeate into the ground, such as roadways, parking lots, and building roofs). As the amount of impervious surface increases, rainstorm runoff increases in volume, increasing the risk of flooding and increasing the amount of pollutants carried into streams and lakes. An increase in built-up surfaces also limits the infiltration of precipitation, thus affecting the recharge of groundwater reservoirs.
- **Air quality**: The pattern of land use can affect the air quality. If residential areas are located far from shopping and work centres, automobile use and emissions will be higher. If forests or other natural areas that purify air are reduced, local air quality can worsen. Changes in vegetative cover can also lead to local and global climate changes.
- **Global carbon cycle**: More-natural landscapes can capture and store carbon in the soil, decreasing the amount of carbon dioxide in the atmosphere. If vegetation is cut and/or the soil is disturbed, stored soil carbon can be released back into the atmosphere. Land-use changes are considered as one of the most important anthropogenic activities (after the increase of greenhouse gases) that impact climate (Kalnay and Cai, 2002).
- **Quality of life** (aesthetics, recreation, congestion, etc.): Land-use and land-cover changes can affect quality of life when those changes impact landscapes having aesthetic value (scenic views) or when the quality and quantity of the landscapes are reduced in areas that are attractive for recreational activities. Also, the changes in land use and land cover can affect traffic patterns that can have affect congestion.
- **Soil:** Changing land use affects soil functioning[7]. When the soil is covered by impermeable material (soil sealing), the contact between soils, biosphere, hydrosphere, and the atmosphere is interrupted, changes occur in the gas, water and energy fluxes. The barrier effect of the sealing may lead to a concentration of runoff water in and on the adjacent unsealed soils, leading to stimulation of erosion in the vicinity of a sealed area. Sealing also changes the albedo and evaporation of a location resulting in a temperature rise in built-up areas. Turning forest soils or grassland soils into arable land will increase the mineralisation of soil organic matter, which not only will contributes to GHG emissions, but also limits soil capacity to act as a carbon sink. The loss of

[7] Reports of the Technical Working groups established under the Thematic Strategy for Soil Protection – Volume VI. http://ec.europa.eu/environment/soil/pdf/vol6.pdf

permanent cover will increase the risk of soil erosion or even landslides and the intensified soil management might cause soil compaction (due to tillage) and salinisation (because of irrigation).

Land-use modelling frameworks apply a wide range of indicators and additional modelling tools to assess potential impacts of simulated changes in land use. Functional indicators should relate to specific (policy) themes, be intuitively understandable for policymakers, capture the essence of simulation results and discriminate between different simulation outcomes (Ritsema van Eck and Koomen, 2008). Such indicator values can be calculated within the land-use model as is the case with the impacts that are directly related to the use of land. Through using additional information and modelling tools, it is also possible to obtain more elaborate impact assessments on a wide range of environmental and other themes as is discussed further on. Depending on the impact that is being considered, different resolutions will be required taking into consideration the nature of the different driving factors and pressures that result on such specific impact and the feedbacks and interactions between different factors at the different scales. For example, when considering land-use based indicators (e.g. available land-use types, spatial distribution of specific land use, soil sealing, urban sprawl, etc) resulting from spatial planning, it is necessary to perform the analysis at the grid level. Also in the case of flood risk, traffic congestion, or water shortage it is necessary to take into consideration changes at the local-grid level.

In the case of other impacts, such as the variation of the emission of ammonia, methane and N_2O resulting from changes in agriculture, habitats fragmentation or vegetation distribution, the main drivers of change mainly act at the regional level and therefore a resolution at the NUTS scale will be necessary.

Sections 5.3.3. describes how such indicators are generally calculated, while Section 7.1. introduces a number of possible modelling tools for impact assessments.

4.2.5. POLICY RESPONSES

4.2.5.1 Overview of policy responses

Land-use conditions in Europe are specific and complex. As commented earlier, policy is one of the key drivers leading to land-use change but it is also one of the responses of society to observed negative land-use patterns (for example, in the case of spatial policies and restrictions such as in the case of nature conservation legislation). Therefore, improved understanding of the decision making processes related to land-use management provides the foundation for evaluating the interactions between factors influencing human activities and feedbacks within the coupled human-environment system (GLP, 2005).

Most of the policies that directly influence land-use change are drafted and applied at the local or regional level, leaving little room for a direct influence by the EU.

Nevertheless, some international policy and policy dialogues often set the precedent for national-level policies, and therefore can be very important, their influence being felt even at local levels. Indeed, some EU initiatives and policies have a considerable direct or indirect impact on land-use developments and the need to preserve the European landscape is now an important topic on the EU political agenda. In general, policy response may aim at:

- Strengthening the land services and provision of multiple land services (multi-functional and sustainable land use) such as:
    - National landscape and nature conservation legislation
    - EU and national rural development legislation
    - EU Forest strategy
    - Structural and cohesion fund regulations
    - EU Soil Framework Directive
- Regulating, supporting and guiding land uses, especially those relating to agriculture, forestry and development (land-use planning), in order to reduce the potential negative impacts of land use changes such as in the case of
    - Local and regional open-space preservation policies
    - SEA and EIA Directives
    - Nitrate Directive
    - Water Framework Directive
    - EU and national strategies to reduce greenhouse gas emissions
    - EU level agriculture legislation especially relating to the rules established for cross compliance

As shown above, some policies exist at the EU level that promote, to a different extent, sustainable land-use practices. For example, the European Landscape Convention promotes the establishment and implementation of landscape policies aimed at landscape protection. Also, the Thematic Strategy on the Urban Environment, adopted in 2006, highlight the importance of sustainable land-use policies which avoid urban sprawl and the loss of natural habitats and biodiversity, and reduce soil-sealing. The Birds Directive and the Habitats Directive have lead to a strong degree of protection for selected natural areas and limit the potential land uses in those areas. It is important to highlight that part of the effectiveness of nature protection can be attributed to other planning objectives and related spatial constrain that are present locally in natural areas. For example, flood retention, coastal defence and groundwater preservation are planning objectives that are often associated with natural areas. These objectives are less likely to be associated with agricultural areas because of their location, management practice and higher investment costs (Koomen, 2008). Another example of policy response to land degradation is the Thematic Strategy on Soil Protection and the proposal for a Soil Framework Directive. The latter requires MS to act upon soil degradation and to ensure a sustainable use of soil. Other EU sectoral policies such as the Common Agricultural Policy (CAP) and the EU Biofuel directive are likely to have a significant impact on the provision of land services.

Open space preservation policies mostly aim at managing urban growth through approaches such as zoning, urban growth boundaries, transfer of development rights and related financial instruments (Koomen, 2008). These policies are mainly applied to agricultural land but are usually not drafter to preserve the qualities of this type of landscapes. Policies aiming at preserving agricultural landscapes are mainly tuned to strength their economic basis, for example through the EU LEADER + programme[8].

A list of the key EU policies relating to land-use choices is presented in section 4.2.5.2. It includes both environmental and other policies where environmental integration has been or will be a key variable for policy definition.

Efforts are currently been made on the development of policies that guide spatial developments in such a way that social and environmental conditions are taken into consideration, whilst also meeting other objectives related to, for example, economic development, water management and biodiversity conservation. On the other hand, reconciling these often conflicting objectives can be a difficult task. Section 4.2.5.3 explains the main trade-offs that have to be taking into consideration in policy making aiming at a sustainable use of land.

4.2.5.2 Key EU policies related to land-use choices

EU Environmental Policies

- European Landscape Convention

The European Landscape Convention was adopted on 20 October 2000 in Florence (Italy) and came into force on 1 March 2004 (Council of Europe Treaty Series no. 176). It promotes the establishment and implementation of landscape policies aimed at landscape protection, management, and planning through the adoption of specific measures.

- Impact assessment of new developments

The Directive on Environment Impact Assessment (EIA) for projects and the Directive on Strategic Environmental Assessment (SEA) for plans and programmes are the two main policy tools used for analysing the impact of a proposed development. These

8 Leader+ is one of four initiatives financed by EU structural funds and is designed to help rural actors encouraging the implementation of integrated, high-quality and original strategies for sustainable development, it has a strong focus on partnership and networks of exchange of experience.

policies make sure that significant environmental impacts are identified, assessed, and taken into account throughout the decision-making process.

- Strategy on the Urban Environment

One of the major challenges for policy-makers is to adopt a sustainable and integrated approach to urban development and management that works in harmony with natural systems rather than against them. The Thematic Strategy on the Urban Environment was adopted on 11 January 2006[9] which highlights that the integrated management of the urban environment should foster sustainable land-use policies which avoid urban sprawl and the loss of natural habitats and biodiversity, and reduce soil-sealing. It also requires taking into account land-use issues in transport planning. This strategy identifies a number of environmental problems which could be improved by the development and implementation of sustainable urban transport plans (SUTPs). Following the Commission's commitment within the Thematic Strategy on the Urban Environment, a Guidance document on Integrated Environmental Management Plans (IEMP) has been elaborated by DG Environment.

- Coastal Zones

In view of the increasing pressure on coastal areas, it is important to improve the planning, management, and use of Europe's coastal zones. The Commission is working to introduce a coordinated policy for the coastal zone regions of the EU. The Commission's 4 year Demonstration programme (1996-2000) has shown that Integrated Coastal Zone Management (ICZM) approach offers the best prospects for Europe's coastal zones. The main instrument to promote this approach is the 2002 EU Recommendation that urges MS to put in place national strategies for an ICZM which promotes an integrated territorial approach that could also be beneficial for other areas such as mountains, wetlands, and other sensitive areas. Besides continued research and project support for coastal zones, the Commission started in 2002 a major Europe-wide project on coastal erosion. During 2006 and the beginning of 2007, the Commission reviewed the experience with the implementation of the EU ICZM Recommendation. A recent communication[10] presents the conclusions of this evaluation exercise and sets out the main policy directions for further promotion on ICZM in Europe.

- Conservation Policies

Over the last 25 years, a vast network of over 26,000 protected areas called Natura 2000 has been created covering all the MS. This represents a total area of around 850,000 km^2, representing more than 20% of total EU territory[11]. The legal basis for the Natura 2000 network comes from the Birds Directive (1979) and the Habitats Directive

[9] http://ec.europa.eu/environment/urban/home_en.htm
[10] COM(2007)308 final of 7 June 2007 http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:52007DC0308:EN:NOT
[11] NOTE: In 2006, prior to the accession of Bulgaria and Romania

(1991). Also, the biodiversity communication[12] highlights the important link between land use and biodiversity loss and the decline of ecosystem services, as well as the potential of their impacts on human well-being. All these policies will lead to a strong degree of protection for selected natural areas and limit the potential land uses in those areas.

- Water Policies

The Water Framework Directive recognises the importance of land-use changes on water quality and availability. It requires MS to collect and maintain information on the type and magnitude of the significant anthropogenic pressures to which the surface water bodies in each river basin district are exposed to, and in particular, to estimate land-use patterns, including identification of the main urban, industrial, agricultural areas, and where relevant, fisheries and forests.

In recognition of the acuteness of the water scarcity and drought challenges in Europe, the European Commission adopted a Communication[13] on July 18th 2007 addressing the challenge of water scarcity and droughts in the European Union. The Communication provides a fundamental and well-developed first set of policy options for future action, within the framework of EU water management principles, policies, and objectives. It recognises land-use planning as one of the main drivers of water use and highlights that inadequate water allocation between economic sectors results in imbalances between water needs and existing water resources. It requests for a pragmatic shift in order to change policy-making patterns and to move forward effective land-use planning at appropriate levels.

Flood management is also an important policy area affected by land-use changes. The recently adopted Directive 2007/60/EC on the assessment and management of flood risks requires MS to assess if water courses and coast lines are at risk from flooding, to map the flood extent and assets and humans at risk in these areas, and to take adequate and coordinated measures to reduce this flood risk. It also requires MS to take into consideration long-term developments, including climate change, as well as sustainable land-use practices in the flood risk management cycle addressed in this Directive. The 'Climate changes Spatial Planning' research program in the Netherlands is analysing these specific issues and is involved in the development of a Decision Support System that demonstrates the impact of different safety strategies on land-use patterns and related flood risks (Van der Hoeven et al., 2008).

[12] COM/2006/0216 final: Communication from the Commission - Halting the loss of biodiversity by 2010 - and beyond - Sustaining ecosystem services for human well-being http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:52006DC0216:EN:NOT

[13] COM/2007/0414 final: Communication from the Commission to the European Parliament and the Council - Addressing the challenge of water scarcity and droughts in the European Union http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:52007DC0414:EN:NOT

- Climate change

About 25% of global greenhouse gas emissions can be attributed to land-use changes, among which tropical deforestation is the most prominent. The Green Paper on Adaptation to climate change require minimum requirements for spatial planning, land-use and land-use change, with respect to adaptation as they could play a key role for awareness raising among the public, decision makers and professionals and for triggering a more proactive approach at all levels. At the local level, it proposes, for example, to explore detailed land management and land-use practices in partnership with farmers to prevent erosion and mud streams reaching houses and settlements. Carbon sequestration in agricultural soils by some land management practices can contribute to mitigating climate change.

- Soil Protection

The Thematic Strategy on Soil Protection[14] and the proposal for a Soil Framework Directive[15] note that soil is a vital source affected by land-use choices. European soils are degraded due to irrational land-use and land-use changes, unsustainable forms of agricultural use, climate change, and a range of other factors. Phenomena such as erosion, decline of organic matter, salinisation, compaction, landslides, contamination, and soil sealing affect soil quality to some extent in all the MS. The proposal for a Soil Framework Directive request MS to act upon soil degradation. To this end, MS must ensure a sustainable use of soil. If soil is used in a way that hampers its functions, mitigating actions must be undertaken. MS will identify the areas where there is a risk of erosion, decline in organic matter, salinisation, compaction, sealing, and landslides. As far as contamination is concerned, MS will set up an inventory of contaminated sites and will then have to act upon the risks identified by adopting programmes of measures for the risk areas, national remediation strategies for the contaminated sites, and measures to limit or mitigate sealing. However, MS are free to decide upon the level of ambition of their soil policy, to set their own targets and to decide how and by when to achieve them. In this context, MS might promote land management practices such as organic and integrated farming, extensive agricultural practices in mountain areas, and mitigate the negative effects of soil sealing, which can maintain and enhance soil organic matter, prevent erosion and landslides, and contribute to flood control and minimising further fragmentation of habitats.

[14] COM (2006)231: Communication on Thematic Strategy for Soil Protection
http://ec.europa.eu/environment/soil/pdf/com_2006_0231_en.pdf

[15] COM (2006)232 final: Proposal for a Directive of the European Parliament and of the Council establishing a framework for the protection of soil and amending Directive 2004/35/EC
http://ec.europa.eu/environment/soil/pdf/com_2006_0232_en.pdf

Sectoral policies

- Transport Policies

Transport infrastructure impacts the landscape in many ways. For example, soil sealing increases the effects of flooding, and the fragmentation of natural areas. The Green Paper on urban mobility (adopted 25 September 2007)[16] addresses the issue of how to achieve a better coordination between urban and interurban transport and land use. Another green paper on the trans-European transport network will be published by the end of 2008.

On July 1996, the European Parliament and Council adopted Decision N° 1692/96/EC on Community guidelines for the development of the trans-European transport network (TEN-T). These guidelines, which establish development priorities, include roads, railways, inland waterways, airports, seaports, inland ports, and traffic management systems. The revision the TEN-T Guidelines is currently being prepared to take account of the EU enlargement and expected changes in traffic flows. The impact of planned infrastructure on land use (e.g. through urban sprawl), biodiversity, and ecosystem services will be addressed in detail, as well as the link with potential changes in land use due to economic trends or climate change.

- Agricultural Policies

The CAP is another EU initiative that has considerable impact on the European land use (Sheridan et al., 2007). In recent years, there have been significant reforms in EU's CAP, involving a shift from the production focus to one that emphasises the need for a broader approach to rural development as well as the maintenance and restoration of environmental quality. Agro-environment schemes were introduced into the EU agricultural policy during the late 1980s as an instrument to support specific farming practices that help to protect the environment and maintain the countryside. The 2003 CAP reform maintained the nature of the agro-environment schemes obligatory for MS, whereas they remain optional for farmers. Some MS have encouraged the practice of woodland coppicing, through the agro-environmental measures, to produce wood-chips to be used in furnaces for domestic and district water and space heating units.

The review of the CAP in 2008 ('health check') and subsequent activities and the implementation of the Rural Development Policies (the essential rules governing rural development policy for the period 2007 to 2013, were set out in the Council Regulation 1698/2005[17]) will have a major impact on future land-use changes.

---

[16] COM(2007) 551 final: Green paper - Towards a new culture for urban mobility http://ec.europa.eu/transport/clean/green_paper_urban_transport/doc/2007_09_25_gp_urban_mobility_en.pdf

[17] Council Regulation (EC) No 1698/2005 of 20 September 2005 on support for rural development by the European Agricultural Fund for Rural Development (EAFRD) http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32005R1698:EN:NOT

- Energy Policies

The EU's renewable energy roadmap sets binding targets for the share of biofuels (10%) and renewable energies (20%) in total fuel and energy consumption by 2020. The Commission's Biomass Action Plan expects a potential increase of energy crops from agriculture from 2 Mtoe in 2003 to 102-142 Mtoe in 2030. The production of biofuels corresponds to a mono-cultural production pattern. The economic incentives involved are sufficient to bring land out of set-aside, and these set-aside areas often have a targeted biodiversity function. The biofuels related policies can influence land-use changes.

- Forestry

The EU Forest Action Plan was adopted on 15 June 2006 which promotes actions with important impact on land-use changes. According to the Action Plan, with support from the EARDF and the Life+ instrument, MS shall:

- develop national afforestation guidelines and promote afforestation for environmental and protective objectives;
- promote agro-forestry systems;
- promote Natura 2000-forest measures; and
- promote schemes for forest owners to engage in voluntary environmental commitments.

- Tourism

In general, tourism does not represent a key parameter affecting land-use patterns in Europe, but this can be important in some regions (e.g. the Mediterranean) where tourism is a fast-growing sector and therefore, the importance of tourism on land-use changes in these regions is significant. The Commission and the tourism stakeholders have recognised the impacts of tourism on the environment and are actively working on the elaboration of a European Agenda 21 for Tourism[18]. This communication, which resulted in the 2007 agenda[19] on a sustainable and competitive European tourism, recognises the need to promote sustainable land-use planning.

EU financial Instruments

EU Cohesion and Structural Funds provide powerful drivers of macro-economic change to support EU integration. However, they can also create inadvertent socio-economic effects that have promoted the development of sprawl and other land-use changes. The Commission's proposals for the Cohesion Fund and Structural Funds for the period

[18] COM(2006) 134 final: A renewed EU tourism Policy: towards a stronger partnership for European Tourism
http://ec.europa.eu/enterprise/services/tourism/doc/communications/com2006_0134en01.pdf
[19] COM(2007) 621 final: Agenda for a sustainable and competitive European tourism
http://ec.europa.eu/enterprise/services/tourism/doc/communications/com2007_0621en01.pdf

2007-2013 include significant opportunities for assistance to address environmental priorities in urban areas, including rehabilitation of contaminated land and integrated strategies for urban regeneration.

The EEA is now working on a report that will evaluate ex-post effects of Cohesion and Structural Funds with studies on its impact on the land uses.

4.2.5.3 Trade-offs while minimising environmental impacts

As mentioned before, modern land-use practices, while increasing the short-term supplies of material goods may indeed undermine many ecosystem services in the long run (e.g. water balance and quality, global carbon and nitrogen cycle, biodiversity, and degradation of soils), not only at the local but also at regional and global scales. Today's society faces the challenge of reducing the negative environmental impacts of land-use practices while maintaining socio-economic benefits. Therefore, comparing land use and trade-offs of ecosystem services and assessing inherent trade-offs between meeting human needs and maintaining the capacity of ecosystems to provide goods and services will be crucial for the future land-use management.

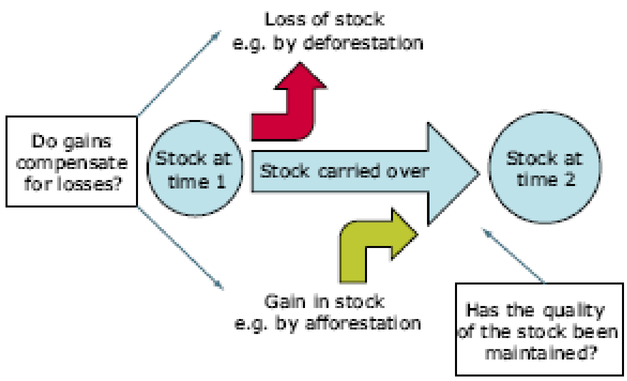
In order to achieve sustainability in land use, it is necessary that policy-makers take into consideration the potential trade-offs between what can often be the conflicting goals. An existing land-cover can be modified, degraded, or destroyed (consumed) and a new type can be generated. Since, generally speaking, land itself cannot be created or destroyed (with exceptions such as coastal erosion and accretion), land-cover change can generally be characterised in terms of different types of flows between land-cover types. Figure 4 presents a conceptual model where the gains and losses (flows) are the transfers of land area between the land-use types.

Several land-use flows can be identified, which are different depending on the authors/research framework. For example, in the Land and Ecosystem Accounts (LEAC) database developed by the EEA, 9 major categories of land-use changes have been indentified:

1. Urban land management
2. Urban residential sprawl
3. Sprawl of economic sites and infrastructures
4. Agriculture internal conversions
5. Conversion of forest and natural land to agriculture
6. Withdrawal of farming
7. Forest creation and management
8. Water bodies creation and management
9. Changes of Land-cover due to natural and multiple causes

Asset accounts in general are relevant to the measurement of progress towards the goal of sustainable development. If human well-being is to be maintained, then either the capacity of natural resource systems to furnish these needs must be retained, or the economy must find a substitute for the natural capital which is capable of delivering an equivalent input.

Figure 4 - Flow accounts for land-cover (EEA, 2006b)



To achieve sustainable land-use practices, it will be necessary to focus and promote the changes that increase the resilience of the managed ecosystem, i.e. practices that enhance its robustness to recover from a disturbance. These include following[20]:

1. Minimise or optimise the use of fertilisers and water
2. Maintenance of soil organic matter
3. Increased green areas in urban landscapes
4. “Agro-forestry” in the sense of nurturing multiple ecosystem services from agricultural systems
5. Biodiversity and landscape management

Policies can promote sustainable land-use practices by taking into consideration the above mentioned possible trade-offs and reconciling conflicting objectives. This complicate task requires precise information on current developments, insight in possible future trends, the preparation of alternative policy measures and an understanding of the impact. In this regard, land use modelling tools can be used to assess to what extent full implementation of these instruments may achieve adequate protection or strengthening of land services. In addition, the land use modelling tools should be able to assess impacts of revisions to existing instruments or new instruments.

[20] Source: Foley et al., 2005

This page is left intentionally blank.

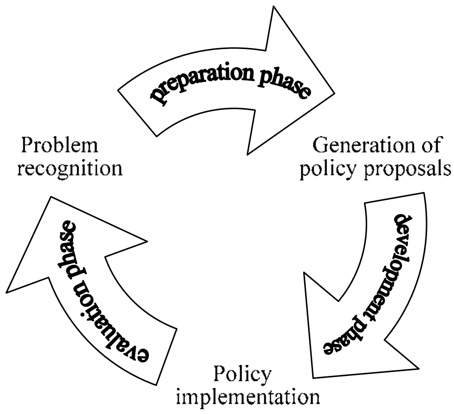
5. IDENTIFICATION OF RELEVANT PROJECTS/MODELS

Land-use change modelling helps in understanding the complex cause-effect relationship between land use and various competing sectors. Thus, the models predicting land-use changes caused by different policy measures can provide valuable information on possible future land-use configurations. A before-hand idea of these possible configurations is crucial for policy makers dealing with issues such as urbanisation, deforestation, water management, and erosion control.

5.1. APPLICATION OF LAND-USE MODELS IN POLICY MAKING

Simulations of land-use changes and their potential consequences can provide most useful information in studies related to the preparation, development and evaluation of large-scale spatial plans and strategies. Figure 5 presents different phases of the spatial planning process as a cyclical activity (Koomen et al., 2008a). These phases correspond to the following steps distinguished by the European Commission for Impact Assessments (IA), (EC, 2005): 1) Identify the problem; 2) Define the objectives; 3) Develop main policy options; 4) Analyse their impacts; 5) Compare the options; and 6) Outline policy monitoring and evaluation.

Figure 5 - Spatial planning process as cyclical activity



During the *preparation* phase, simulations of future land use provide policy makers with impressions about the consequences of current developments they will have to face in the future. Based on the results of the simulations, the need for actions can be assessed and the drafting of policy proposals initiated. During the *development* phase, the possibility to implement different alternatives is assessed. The application of land-use models in the *evaluation* of the impacts of actually implemented policies and strategies is rare, but some examples (e.g. Geurs and van Wee, 2006).

Dekkers and Koomen (2007) discuss three different methods that can be used to create simulations of (future) land use for planning purposes: *trend analysis*, *impact assessment,* and *scenarios studies*.

Trend analysis can be used to simulate the possible future state of land-use systems on the basis of observed current trends, developments, and policies. This is a representation of autonomous developments that is, for example, helpful in enabling policy makers to make decisions on investments in additional hydrologic infrastructure that is needed because of continuing urbanisation.

Impact assessment typically analyses the possible developments that are caused by a specific, spatially explicit, plan or project. These studies might be combined with trend analysis to specifically assess the additional impact of the selected project under different policy options.

Scenario studies are especially suited for long-term studies that deal with a wide array of possible developments and the implied uncertainties. Using scenario analyses allows indicating possible future land-use patterns according to the specified scenario conditions. Based on this knowledge, policymakers can assess the need for action and select the most appropriate policy measures. Since the scenarios can also contain reference to actual or envisaged spatial policies, the simulations offer a depiction of their possible outcomes. Policymakers can thus be confronted with the likely outcomes of their decisions.

Another, rather specific approach that generates possible alternative solutions to land-use allocation problems is offered by optimisation techniques. These calculate an optimal land-use configuration based on a set of prior conditions, criteria and decision variables (see, for example, Loonen et al., 2007).

5.1.1.1 Application of land-use models in the Netherlands

The Netherlands has considerable experience in the application of land-use modelling tools in policy making. Acknowledging the fact that many environmental and ecological problems are related to land-use developments, the Dutch government wanted to gain further insight into spatial changes in the future. For this purpose, the Netherlands Environmental Assessment Agency (MNP) participated in the development of the Land Use Scanner (1997) and the Environment Explorer (1998) modelling tools. These modelling tools have, amongst others, been mainly applied in the following contexts:

- Environmental Outlooks
- ex-ante evaluation National Spatial Policy Plan
- Sustainability Outlook 1 and 2

The Netherlands Environmental Assessment Agency (MNP) was also active in the application of UrbanSIM (2005) and CLUE (2003). Furthermore, the tool EURURALIS 2.00 has been applied under the motion in Parliament for assessing the future of the

Dutch agriculture (2002), and for investigating the potential impacts of biofuels (2006). Following are some advantages of the use of such modelling tools (Borsboom-van Beurden, 2008):

- Integrative frameworks allowed visualising sectoral policies, trade-off and potential conflicts.
- The development of such modelling tools is an interactive process towards the end-product, which is as important as the actual final results for policy-makers (from a learning point of view).
- Modelled results allowed to set agendas for policy-makers as the results had a "signal function".
- Modelling tools provided insights into the pressures of land-use changes on agricultural land, valuable landscapes, nature areas, and flood prone areas.
- Modelling tools provided results that showed possibilities and best options under certain conditions, and also options for policy optimisation.

On the other hand, certain limitations were also encountered when using such land-use modelling tools, including:

- Dependency on base data, expertise for allocation rules, coherence of assumptions.
- Wrong expectations due to level of detail.
- Communicating results were sometimes complicated.
- Not all environmental problems could be addressed (e.g. air quality, traffic, water).
- Indicators were not always sufficiently quantified.
- Behavioural components are still missing in existing modelling tools (e.g. human, ecological).

5.1.1.2 Application of land-use models at EU level

There are a number of research projects that address, to different extent, land use changes and the potential impacts these might have. Indeed, over the last years, much progress has been made in the development and application of land-use modelling tools for better analysing future developments and their implications. Scenario development has become a more increasingly used by European organisms. Hereafter we present briefly some examples of European projects involving land-use modelling.

The project PRELUDE of the European Environment Agency (EEA) aimed at developing coherent scenarios to describe plausible future developments for land use in EU25 plus Norway and Switzerland and their potential environmental impacts for the period 2005–2035.

Another research project involving modelling of land uses and environmental impacts is the integrated project SENSOR, which aims at developing an ex-ante Sustainability Impact Assessment Tools (SIAT) to support decision making on policies related to multifunctional land use in European regions. The reform of the CAP is the first policy for which model outputs have been produced within the SENSOR project with the SIAT. The impact of other policies will also be assessed in the future such as subsidising bio energy production, introducing aviation tax, and revision of the water framework Directive and/or soil Directive.

A good example of ex-ante assessments using land use modelling is the recent studies by DG Agriculture on CAP reform SCENAR2020[21]. Under the SCENAR project, a quantitative analysis on the impacts of the different scenarios considered on parameters such as the agricultural income or the employment was performed using simulation models.

The European Commission adopted the ESPON 20006 programme with the aim of applying research and studies on territorial development and spatial planning from a European perspective in support of policy development. Relevant modelling tools have been developed under the EU ESPON project[22], such as the Macro-economic, Sectoral, Social and Territorial (MASST) model, and the Know Trans-European Networks (KTEN) model. KTEN, together with MASST, have been used to precise qualitative scenarios into quantitative ones, providing an economic, spatial and environmental strategic assessment. The Programme 2013 was adopted on the 7th of November 2007.

The MOLAND model is property of the JRC and was developed by RIKS. It has been applied to an extensive network of cities and regions, and since 2004, MOLAND is contributing to the evaluation and analysis of impact of extreme weather events, in the frame of research on adaptation strategies to cope with climate change. Further, the MOLAND model has been integrated with a catchment based hydrological rainfall-runoff model LISFLOOD. One specific application of this integrated modelling scheme is to provide planning elements to prevent and mitigate the effects of extreme weather driven events such as flood and forest fires.

The MedAction PSS, commissioned by EC and developed by RISK, assesses physical, economic and social aspects of land degradation and desertification, sustainable farming and water resources. It has been applied in Northern Mediterranean coastal watersheds. It has been applied to the Guadalentın river basin in Spain, Alentejo (Portugal), Val d'Agri (Italy) and Lesbos (Greece). Other future applications include MedAction is the updated version of MODULUS, and is currently being further developed in FP-6 project DeSurvey.

These are just a few of the modelling relevant tools that have been developed recently in Europe and that integrate land-use changes modelling. It can be observed that

[21] http://ec.europa.eu/agriculture/publi/reports/scenar2020/indextech_en.htm

[22] More information available at: http://www.espon.eu/

European institutions such as the Commission, JRC and the EEA have supported and collaborated in the development of this type of tools. Nevertheless, it the application of this type of tools in policy-making at the European scale is still very limited.

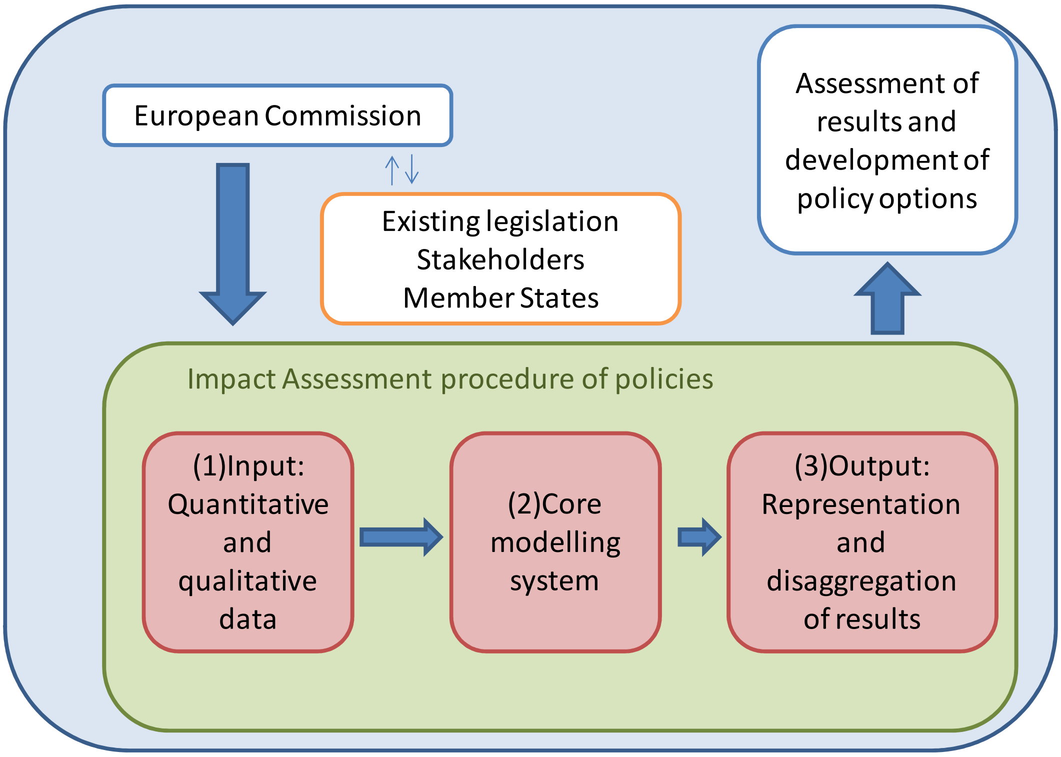
5.2. AN EU MODELLING FRAMEWORK FOR IMPACT ASSESSMENT

Impact assessment is an emerging scientific field that involves a wide range of disciplines and methods. In order to substantiate impacts assessment procedures and develop science-based tools, the European Commission has launched a number of research projects (e.g. under the sixth framework programme), some of them aiming at developing modelling tools for supporting policy decision. Appendix 6 presents a non-exhaustive list of different projects and programmes at the European level that have already delivered or are likely to deliver an input relevant for modelling of EU land-use choices and the potential environmental impacts.

It has been suggested previously that multi-sectoral approaches covering a wide range of scales are needed in order to be able to take into consideration the different driving forces of land-use change that operate from local to global levels (Verburg et al., 2008).

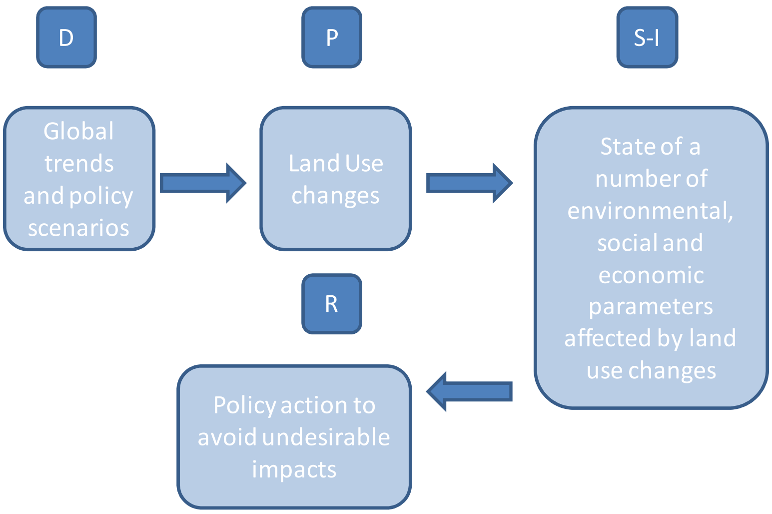
In general, a relevant modelling framework should be capable of translating the policy questions into alternative scenarios that could be compared through a set of indicators that capture key economic, environmental, social, and institutional issues. The set of indicator values can be further expanded by using an intelligent linkage of quantitative models, which rely on available relevant data. Figure 6 represents the generic concept of such a modelling tool in the context of the European policy making.

Figure 6 - Context of the use of modelling tools in European policy development



Considering the DPSIR framework, the analytical chain could be defined as shown in figure 7. There are a number of drivers such as the socio-economic and technological situation that, along with the land-use policies are going to induce those land-use changes. As a consequence of land-use changes, different social, economic and environmental parameters are going to be affected. Policy response should follow to avoid the undesirable impacts of certain policies based on the results of the analysis.

Figure 7 – Analytical chain according to the DPSIR framework



From a conceptual point of view, the main components of such a modelling framework in the context of ex-ante impact assessments can be divided in several phases: pre-processing, the core modelling system (to predict the impacts caused by land-use changes), post-processing (presentations of output results in different formats), and, additionally, a policy support system (PSS) to allow policy makers and other interested parties to simulate easily policy scenarios and their environmental, social, and economical impacts.

5.2.1. PRE-PROCESSING PHASE

The first step is the elaboration of general framework, which includes defining scenario specific conditions and background assumptions, for example, regarding the demographic and economic trends, world trade regulations, and consumer preferences that are going to influence directly or indirectly land use. The background framework, which can also be called "narrative scenario", enables the users, i.e. policy experts and modellers, to define their hypothesis regarding the driving forces for each scenario. Another important aspect to take into consideration when defining scenarios is the policy context and the policy issue that is to be analysed. Once the policy question is defined, it is easier to determine the relevant frameworks, which will form the basis for the formulation or description of scenarios.

During this pre-processing phase (corresponding to box (1) in figure 6) the data acquisition and manipulation is done to make it suitable for the core modelling system. This includes the analysis and harmonisation of the input data from different sources and its aggregation and disaggregation at various levels. Usually, all the required data sets have to be integrated into a common data structure in terms of content, spatial coverage, and hierarchy. The data handled may include spatial data (e.g. LEAC), socio-economic data including future projections for different growth trends, and environmental quality data (biodiversity, water quantity and quality, etc.).

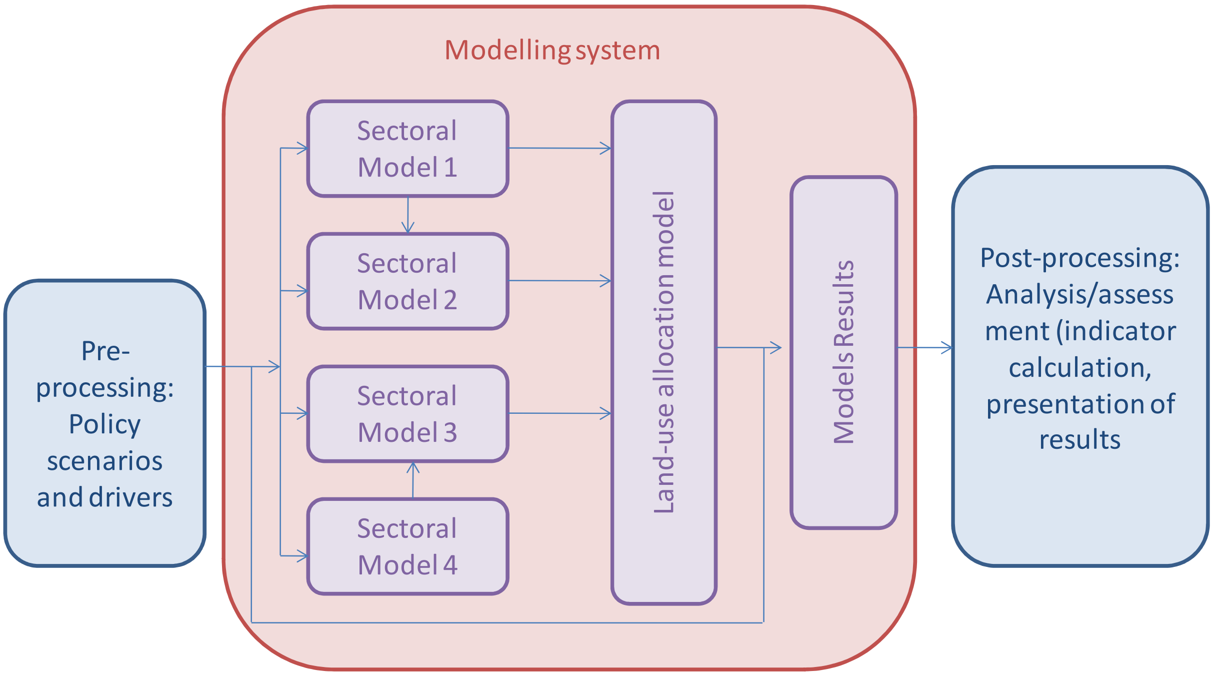
5.2.2. CORE MODELLING SYSTEM

The core modelling system (box (2) in figure 6) has the objective of quantifying the impacts caused by land-use changes. To this end, different models are required in order to determine the intra-sectoral interrelations, feedbacks, and land claims. In some cases, such sectoral land claims have to be estimated with the help of existing models that have been adapted to fit the specific modelling framework or with new modules that may have to be developed. Furthermore, a spatially explicit land allocation model is usually required in order to allow for modelling of competition between land uses and quantification of changes in land use. It takes into consideration demographic change, and spatial policies (assumed) location factors and the estimated land-use requirements dictated by various policies and the estimated sectoral specific claims. The configuration of the different models might vary considerably, but they usually interact in a consistent way and variables stemming from sector models are usually fed back into others (e.g. macroeconomic model) in an interactive way until convergences are achieved. Following are some examples of models or sub-models that can be use in the modelling system:

- Model(s) to predict land use by urbanisation, taking into consideration, for example, inherent suitability for different land uses; transport networks; zoning status (i.e. legal constraints) for different land-use classes, and socio-economic factors (e.g. population, income, production, employment).
- Model(s) to predict transport flows, taking into consideration, for example, the transport activity forecast, transport prices forecast, road pricing, public transport pricing, size and composition of vehicle stock in the base year(s) and projected years, and policies on emission standards, subsidies for cleaner cars etc. These models provide valuable input to land-use change models as they describe an important driver of land-use change.
- Model(s) to predict the land use by agriculture, taking into consideration, for example, as in the CAPRI model, agricultural policies in the CAP, market prices of agricultural products, feed, N, P, K fertiliser, and diesel or plant protection costs by agricultural activity.
- Model(s) to predict land use by nature conservation taking into consideration, for example, the interaction between policy strategies and changes in land use (agriculture, forestry, settlements), climate change, infrastructure, fragmentation, nitrogen disposition, etc.
- Model(s) to predict land use by forestry, taking into consideration, for example, the current forest distribution, forest management (tree mortality, yield, and felling regime), and the market demand for wood.
- Macroeconomic model that makes the distribution of land claims between the sectors on national or regional level.

Figure 8 presents the schematic representation of the core modelling process.

Figure 8 – Core modelling process



5.2.3. Post-processing phase

During this phase, the results of the core modelling system are analysed and the results presented in terms of sets of indicators representing different social, economic, and environmental aspects of the land-use changes. Some indicators can be based on the simulated land-use changes themselves (e.g. rate of land-use change for a specific land-use type, hot spots of land-use change) while others reflects the social, economic and environmental changes resulting from the changes in land use.

Some examples of such indicators are:

- Ecological indicators such as global warming potential, noise, water surface runoff, N input, soil erosion, loss of natural areas, endangered species loss, food risk, open space loss, etc.
- Economic indicators such as cost of land, congestion on the road system, export/import rate, budgetary expenditure, etc.
- Social indicators such as income per capita, employment rate, residential density, population density, etc.

The results are presented both in graphical and numerical form. Some examples of such output are land-use change maps, indicators maps, tables of aggregated national and regional indicators, etc. In order to presents results from modelling, Geographical Information Systems (GIS) are often used. Finally, this module should provide all the required data necessary for simulating various scenarios in the PSS for performing the scenario analyses, as explained is the following sub-section.

5.2.4. Policy support system

This type of system is built on the top of a land-use modelling framework and using the output of the core modelling it could perform scenario analysis for different policy options. This system can also feed the common policy assumptions into the model(s) in previous phases so as to avoid re-running the model(s) while performing policy analysis. This system can have specific modules to define various scenarios based on time (e.g. baseline and projection years for ex-ante assessment), space (region, MS, EU), and policy choices. This policy support interface has to visualise the analysed scenario impacts in such a way that they are easily understandable by the decision makers, for example, with maps or trend curves. Such easy-to-use PSS can be useful to assess different scenarios of a specific policy issue (independent application).

5.3. RELEVANT RESEARCH PROJECTS

As mentioned earlier, there are a number of research projects that address, to different extents, land-use changes and their potential impacts. During the last few years, much progress has been made in better predicting future land-uses changes though not much of this research focuses on the environmental impacts of such changes. In this sub-section we explore existing models and modelling frameworks for each phase of a generic land-use modelling framework, as described in section 5.2.

5.3.1. Pre-processing phase

In this subsection, we discuss the policy questions addressed in different existing land-use models or model frameworks, as well as the policy scenarios used and the drivers considered. This information is summarised in Appendix 7. We observe that the majority of the modelling frameworks that have been designed and applied to date mainly deal with policy questions related to agricultural policies, in particular the impacts of the CAP reform and changes in the support to rural development. Consequently, the scenarios in these models have been elaborated mainly for land use in the context of agricultural policies e.g. different degrees of global market integration and different levels of regulation, such in the case of the scenarios defined for EURURALIS 2.0[23]. The elaboration of scenarios does also usually require the quantification of exogenous variables, such as demography, trade barriers and technology parameters, representing the developments assumed for each scenario (Verburg et al., 2008).

[23] For more information on the EURURALIS 2.0 http://www.eururalis.eu/eururalis2.htm

5.3.2. CORE MODELLING SYSTEM

As mentioned before, the core modelling system of a modelling framework can be constituted by different types of components, which will be selected according to the specific policy questions that are addressed and the potential impacts analysed. A complex modelling tool, understood here as a whole set of models, can include, for example:

- sectoral models, which area going to estimate the regional demands and restrictions for land-use change for different sectors (e.g. agriculture, forestry, tourism, biodiversity protection, etc.)
- global models, which provide information on global demand and supply (consumption and production levels at different prices) on products and world market prices
- land-use allocation models, which to define potential land use changes in the future taking into account the demands from different sectors, suitability factor , attractiveness and spatial policies.

The different models are linked by means of an interface or software infrastructure that is going to allow different feedbacks between them.

Using the above presented general classification of models, hereafter provides some examples of existing models being used in different European modelling frameworks. For example, the models CAPRI, EFISCEN, and ASTRA can all be considered as sectoral models, with results provided at the regional scale, usually in NUTS. Some models have been used in different modelling frameworks. For example, the land-use model CLUE-s is one of the most used land allocation models globally, used for example in the modelling framework Eururalis 2.0 and SENSOR SIAT.

Table 1 - Examples of existing models being used in different modelling frameworks

Model type	Model	Models Characteristics: Theme	Models Characteristics: Geographical resolution	Modelling framework using the component
Global models	LEITAP	Economy	Global/EU/national	Eururalis 2.0
	IMAGE	Ecological-Environmental	Global	Eururalis 2.0
	NEMESIS	Economy	Global/National	SENSOR SIAT
Sectoral models	CAPRI	Agriculture	NUTS2 to grid	SEAMLESS-IF, SENSOR SIAT
	ESIM	Agriculture	EU/national	
	EFISCEN	Forestry	National/Regional	SENSOR SIAT
	ASTRA	Transport	NUTS2	
	PHOENIX plus	Demography	National to grid	Eururalis 2.0
Land Use Models	CLUE-s	Land use	Grid	Eururalis 2.0, SENSOR SIAT
	Land Use Scaner	Land use	Grid	
	METRONAMICA	Land use	Grid	MOLAND model, LUMOCAP, Environment Explorer

Sectoral models

As discussed earlier, no single model is able to capture all key process essential to explore land-use changes in Europe at different scales relevant to make a full assessment of driving factors and impacts. Therefore, many recent modelling tools use a series of different models in order to be able to consider the different trade-off between sectors across a range of scales (from EU-27 to MS and regional levels).

The sectoral models or sub-models that can be used vary depending on the policy questions that are addresses. The Table 2 summarises some information on different sectoral models.

Some of these models allow estimating the land-use requirement for each sector, which are different depending on the scenarios that are considered. For example, in the case of the SENSOR SIAT prototype, the sector models are CAPRI for agriculture, EFISCEN for forestry, SICK for urban, B&B for tourism and TIM for transport infrastructure.

Table 2 – Non-exhaustive list of sectoral models related to land-use change

Model	Sector	Geographical coverage	Geographical resolution
CAPRI-Dynaspat (Common Agricultural Policy Regionalised Impact	Agriculture	EU27, Norway and 6 Western Balkan countries	Regional level (administrative regions, NUTS2) and 1x1 km grid
ASTRA (ASsessment of TRAnsport strategies	Transport	EU15	NUTS 2
EFISCEN (European Forest Information Scenario Model)	Forestry	EU27, Switzerland and Norway	National to provincial level (depends on inventory database)
SCENES	Transport	EU 15 plus Bulgaria, Czech Republic, Estonia, Hungary, Lithuania, Latvia, Poland, Slovenia, Slovakia, Romania, Switzerland and Norway	NUTS 2
PHOENIX plus	Demography	Global (in Europe 40 countries)	Country level, disaggregated to 0,5 x 0,5 degree grid
GLOBIO	Biodiversity	Global	1km x 1km grid
Euromove	Biodiversity and climate change	EU 27	50km x 50km grid
Prometheus	Energy	Global	
RAINS	Air pollution (energy, transport and agriculture)	Almost all European countries	Country level
TREMOVE	Air pollution (energy and transport)	EU15 countries plus Czech Republic, Poland, Slovenia, Switzerland and Norway	Country level.
WEM (IEA's Word Energy Model)	Energy	Global	21 regions

In the case of the modelling framework of the SEAMLESS project, key models are APES, FSSIM, EXPAMOD, SEAMCAP and CAPRI, which simulate different aspects of the farm system at different levels of organisation (Van Ittersum et al., 2008). The agricultural sector model SEAMCAP simulates supply-demand relationships for agricultural commodities for EU-25 from the farm system model (FSSIM) through an econometric meta-model EXPAMOD. The farm system models in turn simulate farm behaviour and uses agricultural activities (e.g. crop rotations) assessed though a mechanistic simulation model for agricultural production and externalities (APES). In this integrated framework, 2 model chains can be distinguished: the APES- FSSIM, establishing the impact between a biophysical simulation model and a bio-economic farm model; and the FSSIM –EXPAMOD-SEAMCAP, establishing the linkage of a bio-economic farm model though an econometric procedure to a market model.

- **Global models**

Global models, such as IMAGE, are integrated assessment models that typically consist of licked sub-components representing, for example, population, economic activity leading to demand for agricultural products; technological and other factors that determine how these products are supplied; emissions of radiatively active gases associated with this production; resulting change in atmospheric composition and climate; and impacts of climate change on ecosystems and society. IMAGE results have played an played a key role in several global studies, including the IPCC Special Report on Emissions Scenarios (SRES), the UNEP Third Global Environment Outlook(GEO-3), the Millennium Ecosystem Assessment (MA), the Second Global Biodiversity Outlook, and the Global Nutrients from Watersheds project of the UNESCO Intergovernmental Oceanographic Committee. At the European level, besides been used in the EURURALIS modelling framework, IMAGE results have been used for the Greenhouse Gas Reduction Policy (GRP) (MNP, 2006). A specific group of global models are global economic models, which are usually equilibrium models aiming to explain land allocation by demand-supply structures of the land-intensive sectors. Land is usually allocated according to its relative economic return under different uses (Verburg et al. 2006). Examples of this model include the GTAP model used in EURURALIS or the NEMESIS, used in the SENSOR SIAT.

In EURURALIS 2.0, changes in agricultural land areas are based on the results of the combined simulations with a macro-economic (GTAP) and integrated assessment model (IMAGE) (Eickhout et al. 2008). GTAP calculates the economic consequences for the agricultural system by capturing static features of the global food market, with the dynamics from exogenous scenario assumptions. The output from GTAP is used by the IMAGE model to calculate yields, the demand for land, feed efficiency rates and environmental indicators.

For example, in the case of the SENSOR SIAT prototype, the macro-econometric model called NEMESIS models cross-sector impacts. An important characteristic of NEMESIS is its land-use module which includes three of the five sector models (SICK, TIM, and B&B models), as sub-modules. For example, using the SICK model, NEMESIS calculates land claims by housing as well as commercial and industrial building. Furthermore, NEMESIS derives the land claims for rail and road transport infrastructures from the TIM model, and uses the B&B model to compute the land used by tourism (Helming et al. 2008).

Appendix 8 presents different existing models developed under EU research and addressing different issues that directly influence or are influenced by land-use changes (sectoral and global models). The information presented in Appendix 8 is based on the EEA overview of existing modelling tools that could be useful for the 2010 State of the Environment and Outlook Report[24]. It summarises information on the issues addressed by the different models, the drivers and indicators that are considered, their geographical and temporal coverage and the end-user target group. Besides the models included in Appendix 8, other relevant modelling tools have been developed under the EU ESPON project[25], such as the Macro-economic, Sectoral, Social and Territorial (MASST) model, and the Know Trans-European Networks (KTEN) model. The KENT model is a passenger and freight traffic forecast metamodel to facilitate a strategic analysis of the Trans-European Transport Networks in a wider pan-European and Mediterranean scale. KTEN, together with MASST, have been used to precise qualitative scenarios into quantitative ones, providing an economic, spatial and environmental strategic assessment.

- **Land-use models**

Appendix 9 presents some of the existing land-use models and their main characteristics. A land-use model is usually applied to allocate land-use change based on competition between different land uses and the use of spatial allocation rules. Various modelling approaches exist for modelling land-use change. The actual land-use allocation is based on a set of constraints and preferences that reflect the characteristics of the land-use type, location, and the assumed processes and constraints relevant to the scenario. The diversity of approaches can be explained by the wide range of research questions in which models are used as a tool, and the different scales of application, ranging from the very local to the global extent. Existing models differ in the spatial resolution and extent, underlying concept, and the range of applications.

SENSOR SIAT, for example, uses the land-use model called CLUE-S. CLUE-S disaggregates the land use on MS level computed in NEMESIS down to 1 km^2 grid units, and adds the land-cover types: recently abandoned arable land, recently abandoned grassland, (semi)natural cover, forests and stable areas. It also distinguishes permanent crops from rotational crops. It then re-aggregates the land available for agriculture and forestry to sub-national regions for use in CAPRI and EFISCEN respectively. The EURURALIS 2.00 tool also use this model, getting its information from LEITAP/IMAGE on a European country basis and allocates land use within each European country on a grid level 1 km^2.

A very important aspect that has to be considered when selecting a model is the distinction between spatially and non-spatially distributed models. This is an important

[24] http://scenarios.ew.eea.europa.eu/fol079729/copy_of_fol615122/model_inventory.pdf

[25] More information available at: http://www.espon.eu/

aspect as since it largely determines the type of research questions the model may answer for that application. Spatially distributed models aim at spatially explicit representations of land-use change at some level of spatial detail, in which land-use change is indicated for individual pixels in a raster or polygon. This group of models is, therefore, able to explore spatial variation in land-use change and account for variation in the social and biophysical environment (Verburg et al. 2006).The CLUE-s and the Land Use Scanner models as well as most of the models included in Appendix 9 are spatially distributed models. Non-spatially distributed models focus on modelling the rate and magnitude of land-use change without specific attention for its spatial distribution.

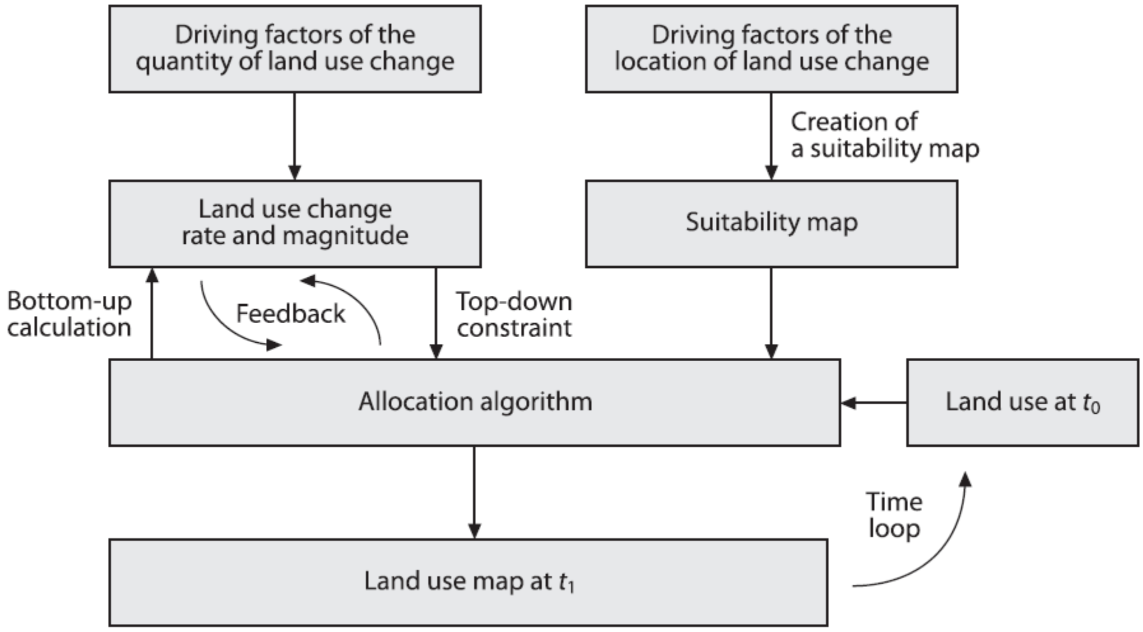
It is possible to identify a common structure valid for a large number of spatially explicit land-use change models. In the model structure a distinction can be made between the calculation of the magnitude of change and the allocation of change. Both calculations are based on a set of driving factors. Based on the interpretation of one or more driving factors that are supposed to be determinants of the location of land-use change a so-called suitability or preference map is created that indicates the suitability of a location for a specific land-use type relative to the suitability of other locations. The selection of the driving factors that are to be used in the model and its translation into a suitability map is one of the main components of a land-use model. A wide variety of approaches exist, including the following (Verburg et al. 2006):

1. rule-based systems based on either theory or expert knowledge;
2. suitability maps based on empirical analysis;
3. transition rules dependent on the land uses in the neighbourhood (e.g., cellular automata).

Figure 9 presents the general modelling chain for spatially explicit land-use change models.

Different approaches have been developed to address spatial autocorrelation in land-use patterns. One of the most popular methods to implement neighbourhood interactions in dynamic land-use change models are cellular automata (CA). In land—use models using cellular automata, the transition of a cell from one land use to another depending on the land use within the neighbourhood of the cell. Cellular automata are used in almost all land-use change models for urban environments (Verburg et al., 2006). The Environment Explorer (property of RIVM/MNP), for example, is an integrated model that uses a CA land-use model with a regionalized, spatial- interaction based economic-demographic location model. The model covers in this case the whole of The Netherlands; the CA has a resolution of 500 m, while the macro-scale model operates on 40 urban-centred economic regions (White and Engelen, 2000).

Figure 9 - Generalised model structure of spatially explicit land-use change models (Verburg et al. 2006)



Land-use models can also be classified by their type of temporal characteristics. When the spatial distribution of the land-use changes is a function of a number of fixed driving factors that do not change over time, the model is static. Such models are often strongly founded in statistical regression analysis that explains past and current spatial developments. This type of models does not account for temporal feedbacks and path-dependencies. Dynamic models, on the other hand, give specific attention to the temporal dynamics of land-use systems, represented by the competition between land uses, irreversibility of past changes leading to path-dependence in system evolution and fixed land-use change trajectories. The CLUE-s model, for example, is dynamic (Verburg et al. 2006). It is based on the dynamic simulation of competition between land uses while the spatial allocation rules can be specified based on either an empirical analysis, user-specified decision rules, neighbourhood characteristics (similar to cellular automata models, see below), or a combination of these methods (Verburg et al., 2008).

There is a wide variety of existing land-use allocation models. Some of them are included in Appendix 9.

There is no single approach that is clearly superior to other models for predicting land-use/cover change. The choice of one land-use model or another will depend on the policy questions that need to be answered, while issues of data availability might also play a role (Verburg et al., 2006; Pontius et al., 2008).

In general, research projects conducted by research teams in Europe usually cover the following themes:

1. Classification, data systems, monitoring and indicators;
2. Impacts of land-use and land-cover change
3. Scenario building and integrated analysis.

It is observed that there is a wide range of inputs, both in terms of existing research projects and recognised research gaps, and a large heterogeneity, from fine detail to the holistic, over various temporal and spatial scales, spanning numerous disciplinary perspectives.

- **Software structure**

The linkage between the different models or modules is usually made with a specific interface or software infrastructure. For example, in the case of the SEAMLESS integrated framework, a shortwave architecture has been created for the SEAMLESS-IF the main component is SeamFrame, which is the core component that runs on a server and provides the services that can be used by the different SEAMLESS components or applications, which include: the modelling environment, the so-called project manager, the processing environment and the domain manager. All the model components implement an interface based on the standard Open Modelling Interface (OpoenMI)[26], which provides an standardised interface to define, describe and transfer data between software components that run simultaneously or subsequently (van Ittersum et al., 2008). OpenMI is the main product of the EU 5th framework programme project HarmonIT[27]. The objective of the HarmonIt project was to 'develop, implement and prove a European Open Modelling Interface and Environment (OpenMI)'. The project ended at the beginning of 2006 and consisted of 14 partners.

This software structure of SEAMLESS allows for (re-)using the stand-alone components of the SEAMLESS-IF (APES, FSSIM, and SEAMCAP) as stand-alone models and linking them in order to assess the specific policy questions. Some policy questions might only need some of the components (e.g. policies with a regional focus do not require a full market analysis, only the models APES and FSSIM).

The software framework in SENSOR SIAT does also use OpenMI to plug calculation cores together. Nevertheless, in principle, the framework used in SENSOR is not designed to allow for plugging the different models (CAPRI, EFISCEN, NEMESIS, CLUE-s, etc.) depending on the specific question to be address.

An alternative approach is that by GEONAMICA, a modelling and simulation toolbox developed by RIKS for the development of spatial Decision Support Systems (DSS) featuring multi-scale and multi-models as their core element. A similar framework has been used in MOLAND (developed by RIKS for the JRC), Med-Action PSS (ongoing 6FP project), Environment Explorer (developed by RIKS for RIVM/MNP), and LUMOCAP

[26] http://www.openmi.org/
[27] www.harmonit.org

(developed by a consortium of 4 partners: JRC, Italy; KU Leuven, Belgium; IUNG,Poland; and RIKS, The Netherlands). GEONAMICA is an object-oriented application framework that allows building blocks required for the development of specific models, analysis tools and user interfaces to address specific issues. Typically GEONAMICA will allow combining system dynamics models and cellular models for this purpose. In particular use is made of different kinds of spatial interaction based models, different kinds of cellular automata models, multi agent or other kinds of rule-based models. It is equipped with computational techniques and algorithms for addressing spatial problems, but also with additional analytical tools, visualization tools, and input, import, export and output tools. Variables exchanged between the different components are mostly maps and to a lesser extent single values (Van Delden et al.,2007).

Another useful software structures that can be selected is the Data Model Server (DMS) toolbox for spatial modelling that, for example, underlies the Land Use Scanner. This toolbox allows the configuration of land-use allocation models and the coupling with other modelling components.

- **Modelling structure of the core modelling system**

The modelling structure and particularly the flows of information and feedbacks between the different components of a modelling framework can vary considerably.

Table 3 summarises the modelling structure and the linkage between different sub-components in the case of different modelling frameworks, again depending on the policy issues to be analysed, but also on the modeller's preferences and previous experiences. Even assessing a similar issue, the modelling structure, the feedback between components and the outcome can vary. For example, both the EURURALIS and SEAMLESS modelling frameworks have been created to support decision making for assessing different options related to agricultural policies. Nevertheless, their focus is quite different, and while the EURURALIS modelling framework uses a combination of global economy (LEITAP/GTAP) and integrated assessment models (IMAGE) and the land-use allocation model CLUE-s to downscale the national level changes to the landscape level, the SEAMLESS modelling framework contains and agricultural sector model (SEAMCAP, which is a version of CAPRI), an econometric meta-model (EXPAMOD), a farm model (FSSIM) and a model for de agricultural production and externalities at the farm level (APES).

Table 3 – Modelling structure and flows of different modelling frameworks

Modelling framework/ project	Models/ component	Theme	Characteristics of the modelling structure
SCENAR	LEITAP	Economy	To perform the analysis, a modelling framework is constructed, existing of three economic models (LEITAP, ESIM, and CAPRI), a more ecological-environmental based model framework (IMAGE) and a land-use allocation model (CLUE-s) to disaggregate the outcomes to the landscape level.
	CAPRI	Agriculture	
	ESIM		
	CLUE-s	Land use	
SENSOR	CAPRI	Agriculture	NEMESIS has a land-use module which includes three of the five sector models (SICK, TIM, and B&B models), as sub-modules. For example, using the SICK model, NEMESIS calculates land claims by housing as well as commercial and industrial building. Furthermore, NEMESIS derives the land claims for rail and road transport infrastructures from the TIM model, and uses the B&B model to compute the land used by tourism, CLUE-S disaggregates the land use on MS level computed in NEMESIS down to 1 km^2 grid units, and adds the land-cover types
	EFISCEN	Forestry	
	SICK	Urban	
	TIM	Transport	
	B&B	Tourism	
	NEMESIS	Economic	
	CLUE-s	Land use	
EURURALIS	GTAP	Economy	GTAP calculates the economic consequences for the agricultural system by capturing static features of the global food market, with the dynamics from exogenous scenario assumptions. The output from GTAP is used by the IMAGE model to calculate yields, the demand for land, feed efficiency rates and environmental indicators. The actual downscaling of the national level changes to the landscape level is done by at a spatial resolution of 1 km2 by CLUE-s,
	IMAGE	Ecological-Environmental	
	CLUE-s	Land use	
SEAMLESS	APES,	Production technologies +externalities	The different models simulate different aspects of the farm system at different levels of organisation. The agricultural sector model SEAMCAP simulates supply-demand relationships for agricultural commodities for EU-25 from the farm system model (FSSIM) through an econometric meta-model EXPAMOD. The farm system models in turn simulate farm behaviour and uses agricultural activities though APES.
	FSSIM	Farm	
	EXPAMOD	Economy	
	SEAMCAP	Agriculture	
MOLAND	METRONAMICA	Land Use	The macro-model consists of 4 strongly linked sub-models representing the Economic, Demographic, Land use and Transportation sub-systems. The economic sectors are aggregated into four main categories: Industry, Services, Commerce, and Port activities. The population is assigned to four residential categories: Residential continuous dense, Residential continuous medium, Residential discontinuous urban, Residential discontinuous sparse
	Other sectoral models		

5.3.3. POST-PROCESSING PHASE

The results of the core modelling systems in terms of land-use change are used to calculate relevant socio, economic and environmental indicators. By way of examples, Table 4 summarises the outputs of existing modelling frameworks. The text below discusses this output in more detail. Following this introduction we then describe the way the indicators are developed that describe the listed impacts.

One of the goals of the PRELUDE project is to predict the potential environmental impacts for the period 2005–2035 of predicted land-use development. The project took into consideration the impacts on biodiversity, water quality, soil quality, air quality, and landscape identity. Nevertheless, the analysis of the potential environmental impacts of land-use changes under the different scenarios was qualitative, not quantitative.

Under the SCENAR project, a quantitative analysis on the impacts of the different scenarios considered on parameters such as the agricultural income or the employment was performed using simulation models (LEITAP, ESIM, CAPRI and CLUE-s) and other quantitative analyses. The modelling exercise generates maps that show land use under different scenarios, but it does not analyse the impacts of such changes on the environment. The only environmental indicator that is considered is the effect of the different scenarios on the nitrate balance.

In the case of the modelling tool developed within the SENSOR project (NERI, 2004), a distinction is made between:

- Direct impacts: those related to the evaluation of the outcomes of a policy in terms of reaching policy goals.
- Indirect impacts: those related to likely positive or negative spill-over onto other economic, social or environmental policy areas, the distributive trade-offs and possible win-win situations – and thus the consistency of the intervention in terms of policy integration and better regulation.

In the case of the SENSOR's SIAT, the results in terms of change in land-use management and different environmental, social and economic processes can be characterised by indicators. Nevertheless, one major challenge in the SENSOR project is the linkage between policy options resulting in change in land use or change in land management that in turn results in impact on the different environmental, social and economic processes (the project has not yet finalised, expected for December 2008). A list of indicators has been produced, which corresponds to the identified main impact issues. An analysis of existing indicators that could be taken back in SENSOR sustainability impact assessments and that have been developed under related EU RTD projects has been carried out. Some of this indicators would be assessed quantitatively and other some other qualitatively.

Table 4 – Output of different modelling frameworks

Model/modelling framework	Model type	What it explains (output)
MedAction PSS (currently being further developed within the FP-6 project DeSurvey)	Multi-temporal dynamic modelling framework	It simulates physical, economic and social aspects of land degradation and desertification
Environment Explorer	Modelling tool with linked spatial dynamic models	It predicts social (built-up area), open-space, recreational space, flooding risk, residential density), economic (access to employment, cost of land, congestion on the road system), and environmental aspects (noise and emissions due to traffic and spatial fragmentation) impacts of land-use changes.
Land Use Scanner	Integrated modelling tool that is linked with additional impact assessment models	Land-use changes and related impacts in the fields of urban sprawl, loss of open space, land price, land-use diversity, soil sealing, flood risk, habitat fragmentation, nutrient deposition, water shortage, accessibility, biodiversity.
LUMOCAP PSS	Dynamic cellular Automata model	Impacts of land-use changes on the rural landscape using a set of indicators (to be defined)
SENSOR SIAT	Meta-modelling tool. Mechanistic Interpolation of input variables	Impacts of policies affecting land use on environmental, social and economic aspects. Besides land-use changes, 60 indicators have been identified in total. In the 1st prototype of the SIAT, there were 5 indicators (GDP growth per capita, gross value added, farm and woodland birds, N surplus in water, and unemployment rate).
EURURALIS	Integrated modelling tool with linked spatial dynamic models	Impacts of different policies on rural development (social, environmental and profit aspects). For example, the modelling tool uses biodiversity, carbon sequestration and landscape change as indicators of changes on the planet; employment, agricultural employment and value added per farmer as indicators of the impact on people, and crop production and farm income as indicators of the impacts of land-use chain the case of the profit dimension.
SEAMLESS	Integrated modelling tool with linked spatial dynamic models	A set of environmental, economical, social and institutional indicators. These include in the first prototype: agricultural Income, Money metric (consumer surplus), Profits of the processing industry , Total welfare , Tariff revenues, Budgetary expenditure, Nitrate leaching, Energy consumption due to use of mineral fertilisers , Global warming potential.

The EURURALIS modelling tool analyses the impacts of land-use changes on people, profit and the planet. By combining three models with scenario specific inputs and several impact indicators, EURURALIS results are available on all the domains of people, planet and profit. For example, the modelling tool uses biodiversity, carbon sequestration and landscape change as indicators of changes on the planet; employment, agricultural employment and value added per farmer as indicators of the impact on people, and crop production and farm income as indicators of the impacts of land-use chain the case of the profit dimension. In spite of the progress made, virtually no integrated model or set of models still allow for a proper and complete assessment of the potential environmental but also socio-economical impacts of land-use changes at the national but also regional level resulting from the different EU policies.

Current versions of existing modelling frameworks focus on specific policy questions, e.g. the CAP reform, and environmental related issues are addressed to a limited extent. Regarding the representation of results, analysed modelling frameworks usually use maps and indicator tables.

- **Indicator development**

Indicators are quantitative measures that help with the interpretation, comparison, and evaluation of simulation results. They basically help describe the state and trends in land use and their related impacts in order to formulate adequate policy responses. As such they relate to the third (***State***) and fourth element (***Impact***) of the DPSIR framework introduced in Section 4.2.

The European Environment Agency (EEA) has developed a Core Set of Indicators (CSI)[28] that describe the ***state*** of the environment. These aim to provide a manageable and stable basis for indicator reporting by the EEA, prioritise improvements in the quality and geographical coverage of data flows, and streamline EEA/Eionet contributions to other European and global indicator initiatives. To date, 35 CSI have been developed and published by the EEA related to different thematic areas. The ETC/TE has developed 2 of them, namely 'Land take indicator' (CSI14), which answers the question 'how much and in what proportion is agricultural, forest and other semi-natural and natural land being taken for urban and other artificial land development?'; and the 'Progress in management of contaminated sites' indicator (CSI15). 11 more ETC/TE indicators have been published by the EEA either in some reports and in the EEA indicators web page (e.g. Proximity of transport infrastructure to designated areas, Fragmentation of ecosystems and habitats by transport infrastructures and settlements, Land take by transport infrastructure, Land take by built-up areas, Progress in integrated coastal zone management, Soil polluting activities from localised sources, Progress in management of contaminated sites, Expenditures on remediation of contaminated sites, Soil erosion from agricultural land, Aral sea follow-up problems, Area of land affected by salinisation). Other indicators currently under revision and not published yet. Some of these indicators can be considered to be pure land-use indicators while other are enhanced land-use indicators, according to the classification discussed above.

To assess the socio-economic and environmental ***impacts*** introduced in Section 4.2.4. many of the land-use modelling environments introduced in the preceding section are equipped with specific indicators or coupled with additional modelling tools. Land-use models have recently been applied to asses possible impacts on: habitat fragmentation (e.g. Eppink et al, 2008; Sheridan et al., 2007), water quality and quantity (e.g. Dekkers and Koomen, 2007; Van der Hoeven et al., 2008) and, in combination with climate

[28] Available at: http://terrestrial.eionet.europa.eu/Indicators/CoreSet/csi

change models, global carbon cycles (e.g. Schulp et al., 2008). The broad quality of life topic is covered by many different impact assessment tools that each address a specific issue, such as accessibility (e.g. Geurs and Wee, 2006) and landscape quality (e.g. the LUMOCAP project). Air quality impacts are very difficult to establish as these need very detailed information on, for example building heights and vehicle characteristics that are not available for future scenarios.

From a modelling perspective, different types of indicators can be distinguished depending on the type of information that is used for their estimation and their level of aggregation. The first type is the purely *land-use based indicator* that can be used to characterise changes in land use. Different types of land-use indicators can be distinguished here, including general composition metrics (that quantify the variety and abundance of land-use types without considering their spatial character) and spatial configuration metrics (that refer to the spatial distribution of the available land-use types and focus on their individual patches, i.e. areas of a specific land-use type). All of the well-known modelling frameworks contain these relatively straightforward land-use based indicators. Based on simulated land-use configuration it is also possible to assess specific impacts that are relevant to environmental or policy themes. Purely based on land use it is, for example, possible to assess the amount of soil sealing relevant to hydrological studies or analyse the extent of urban sprawl. The latter can implemented through an analysis of the compactness of urbanisation and the loss of open space (for more details, see: Ritsema van Eck and Koomen, 2008). This type dedicated land-use based indicators is available in most modelling frameworks or can be added without much effort. A second type of indicators is the so-called *enhanced land-use indicator* that relies on additional data from other external sources. These indicators are used to evaluate more complex issues, such as, for example, flood risk. The latter assessment describes the potential future economic damage and number of casualties resulting from a possible flooding. This analysis takes future spatial patterns into account in combination with inundation maps, flooding probabilities, damage functions and current values associated with land-use types. This approach is described elsewhere in more detail (Van der Hoeven et al., 2008) and can assess the potential benefits of specific safety measures. An even more elaborate third type of indicator is formed by the *indicator-model coupling* that combines land-use simulation results with additional spatial models. Examples are offered by the Dutch Environmental Assessment Agency and others to calculate, for example, biodiversity and accessibility impacts (MNP, 2007) and possible water shortages (Dekkers and Koomen, 2007). Table 5 list a number of useful modelling tools that are available to assess land-use related impacts for a number policy issue.

When impact assessments are obtained through the application of indicators it is important to consider that several aspects influence their overall quality. First and foremost, it is evident that any simulation of future land use is based on a wide range of assumptions regarding uncertain socio-economic developments and physical conditions. Simulations should, thus, not be interpreted as predictions but rather as possible images of future developments. These uncertainties are especially large for the high spatial and thematic resolutions that are normally needed to perform impact assessments. Secondly, many indicator assessments are obtained through a combination of different methods and datasets and thus face the risk of mismatches in, amongst others: underlying (scenario-based) assumptions; semantics; and spatial, thematic, and temporal resolutions. Such mismatches may lead to the introduction or propagation of errors that hamper the accuracy and thus applicability of the results. In a European context it is especially important to consider that data sources may to a large extent be derived from individual member states or even smaller entities making it more than likely that transboundary quality issues arise. A third, more complex issue relates to the relations that exist between different (environmental) impacts and the feedbacks that might occur between specific impacts and the use of land. Land-use changes may, for example, lead to changes in accessibility (e.g. congestion) that in turn may lead to additional environmental impacts (e.g. on air quality and eventually health) and a feedback on land use itself (e.g. relocation of firms or residences). Such relations and feedbacks call for truly integrated modelling frameworks that are able to assess impacts while considering their mutual relations and allow for feedbacks to the land use allocation model. To date, many land-use modelling frameworks rely on separate impact models for more elaborate themes and do not offer this full scope of integration.

5.3.4. Policy support system

In general, no advanced modelling tool can be run by non-experts. In order to allow policy-makers to predict the effects of a given policy option and getting a transparent insight on how the models work, for certain models and modelling frameworks, efforts are also put in the creation of an easy-to-use PSS that allows users to browse through a wide set of simulation results that have previously obtained. The results of the core modelling framework for a certain set of scenarios are used as a database for the end-use PSS. This interface does not require expertise and the simulations usually take a few minutes only. This has been done, for example, in the case of the EURURALIS project, the SENSOR SIAT and SEAMLESS.

Regarding the presentation of the results for the end-user, in some cases, e.g. in SENSOR SIAT and EURURALIS, the results can be visualised graphically (e.g. spider diagrams that allow comparison among scenarios). Graphs such as spider diagrams and trade-off curves are more communicative compared to numerical presentation, although they present information in a less detailed way. Another tool for presentation of results is maps. The main advantage of maps is that they allow several indicators to be analysed at the same time in an illustrative and easily understandable manner, on different spatial scales, and consider simultaneously different dimensions of sustainability.

This page is left intentionally blank.

6. COMPARING EXISTING MODELS

In this section, a concise comparative analysis of existing models or modelling frameworks is presented. This section is not meant as an extensive comparison of all identified models, but only serves to indicate the main differences between the different models that relevant for the EC. To facilitate the comparison of the commonly applied modelling frameworks, a structured set of criteria was developed that is presented in Appendix 10.

6.1. RELEVANCY

6.1.1. SIMULATION OF MULTIPLE LAND-USE CHANGES

Most of the European modelling tools mentioned in section 5 can analyse different types of land-use change simultaneously. In this regard, it is important to highlight that the level of detail and the classification itself might differ depending on the policy questions that are being assessed. Many of the existing modelling tools use a classification of land-use types that is similar to the one used in the CORINE Land-cover European database, but adapted depending on specific analytical needs. For example, in the case of the SENSOR SIAT, 17 different types of land uses are considered (aggregated from the CORINE classification). In the case of the EURURALIS modelling tool, 8 different land-use types are used. The land-use classification is usually defined by the land-use model e.g. Land Use Scanner normally distinguishes 15 different land-use categories.

6.1.2. SPATIAL RESOLUTION

Existing modelling frameworks and land-use models have a spatial resolution ranging from 250 m^2 to 1000 m^2. Modelling tools dealing with the EU-25 level, e.g. EURURALIS, enable an analysis at 1 km^2 grid scale.

6.1.3. SIMULATION AT MULTIPLE SCALES

Most modelling frameworks can perform simulations at multiple scales. Nevertheless, some modelling configurations are more suitable for multi-scale simulation. Differences in scientific disciplines have resulted in differences in the levels that are addressed by the different land-use modelling frameworks. More recently, approaches that implement multiple scales can be distinguished by the implementation of a multi-scale procedure in either the structure of the model or in the quantification of the driving variables. The latter approach acknowledges that different driving forces are important at different scales and it takes explicit account of the scale dependency of the quantitative relation between land use and its driving forces. This multi-scale approach has been adopted as mentioned before, in many recent modelling frameworks, such as EURURALIS or SEAMLESS. Within EURURALIS, global interactions determining the production and consumption characteristics of different regions are modelled by economic models at the global scale in connection with integrated assessment models to account for feedback of changes in climate. Land allocation at more detailed scales within the countries of the European Union is done by a spatially explicit land allocation model that accounts for variations in socio-economic, policy and biophysical location characteristics (Verbug et al., 2006).

The Land Use Scanner model and the GEONAMICA application framework have been mainly applied at the national and regional levels so far. In the case of GEONAMICA, its application at the EU-27 level is under development under the LUMOCAP project. The main challenge when applying these models at the EU level is to find the right data describing, for example, location characteristics in a way that they are comparable across national boundaries. Further, this will increase the computing efforts multiple times and it may be important to look it from impact assessment point of view where many simulations might be required in very short time duration.

Another important aspect to take into consideration is that sub-national policies may set strategies and plans having impacts in contradiction to that the ones resulting from the implementation of European and national strategies. Often it is difficult to differentiate the causes of observed land-use changes as it is difficult to determine the complex set of driving forces, which are often a combination of local, national, and European policies. A desirable feature of the expected modelling tool would be the capability to differentiate between various causes originating a specific impact. In principle, it would be possible to define the land-use allocation rules (determined by the specific strategies and plans) at the local level. Nevertheless, a major problem is the availability of information of land-use policies at the local level for the whole EU-27.

6.1.4. APPLICABILITY FOR DECISION MAKING

The type of policy questions that can be addressed and the level of detail of the analysis differ per modelling application. For example, the reform of the CAP is the first policy for which model outputs have been produced within the SENSOR project with the SIAT. The impact of other policies will also be assessed in the future such as subsidising bioenergy production in Europe, introducing aviation tax, and revision of the water framework Directive and/or soil Directive. Nevertheless, the final version of SIAT has not finalised yet and only a first prototype is available. The finalised SIAT will provide quick decision support for policy makers at EU level, allowing choices of policy options and target setting, illustrating cross-sectoral side effects of land-use policies, and comparing regional policy effects with reference scenarios.

Under the EURURALIS and SEAMLESS projects, modelling frameworks have been created to support decision making, in particular for assessing different options related to agricultural policies. In the case of EURURALIS, the results have been integrated in easy to use DSS. These modelling frameworks, with their current configuration and technical characteristics, can address not only socio-economic but also environmental impacts resulting from different policy options in the agricultural sector.

Other modelling frameworks have previously been applied to explore a wide variety of other policy issues. For example, applications of the Land Use Scanner include, amongst others, simulation of future land use following different scenarios (Borsboom-van Beurden et al., 2007; Schotten et al., 2001a), the evaluation of alternatives for a new national airport (Scholten et al., 1999), the analysis of the climate-induced land-use adaptations (Koomen et al., 2008b), assessment of water shortages (Dekkers and Koomen, 2007) and flood risk (Van der Hoeven et al., 2008) and the optimisation of land use following different policy objectives (MNP, 2007). Apart from these Dutch applications, the model has also been applied in several European countries (Hartje et al., 2005; Schotten et al., 2001b). Similar applications can be made at the EU-25 level, but require a new model configuration considering aspects such as the integration of new sector-specific models, new data, calibration, etc.

6.1.5. Time horizon

The time horizon generally depends on the policy issue that are addressed. Usually, time horizons vary between 2015-2050 taking into consideration the life time of different policies. Almost all of the models allow for the simulation of multiple time periods.

6.1.6. Assessment of environmental, social and economic impacts

Most recent modelling frameworks, as the ones introduced in section 5, can simulate the potential environmental, social and economic impacts of land-use change but to a different extent. For example, the EURURALIS uses biodiversity, carbon sequestration, and landscape change as indicators of changes on the planet; employment, agricultural employment and value added per farmer as indicators of the impact on people, and crop production and farm income as indicators of the impacts of land-use chain the case of the profit dimension.

The selection of appropriate indicators and associated calculations is indeed, a very important phase in applying a modelling framework. This is particularly determined by the type of questions (issue to be addressed) that the modelling framework is designed to explore. Furthermore, the indicators that are to be used are also dependent on the type of output from the core modelling module and the sector models that are integrated. Land Use Scanner, for example, can model, ecological impacts, landscape impacts, urbanisation patterns, flood risk, etc. More impact assessments are possible (e.g. accessibility/congestion or transition costs), but in combination with additional models. The same applies to the MOLAND project, where for further assessment, the model has to be linked to other models. For example, MOLAND (property of the JRC) has been applied to an extensive network of cities and regions, for an approximate total coverage in Europe of 70,000 km^2. Furthermore, it has been integrated with the catchment based hydrological rainfall-runoff model LISFLOOD adapted for scenario modelling, flood forecasting, and floodplain inundation modelling. One specific application of this integrated modelling scheme is to provide planning elements to prevent and mitigate the effects of extreme weather driven events such as flood and forest fires (Genovese, 2006).

In the case of the SENSOR SIAT, besides land-use change, about 60 indicators have been identified for analysis. In the first prototype of the SIAT, there were 5 indicators (GDP growth per capita, gross value added, farm and woodland birds, N surplus in water, and unemployment rate).

6.2. MODEL USE

6.2.1. EXPERTISE REQUIRED, MODEL UTILISATION, AND INTERPRETATION OF RESULTS

The creation of a single interface for both policy makers and modellers is usually complicated.

In most cases, some basic modelling experience is required to calibrate, run and in some cases, even for interpreting the results. In such cases, it might be advisable to train policy officers regarding the underlying assumptions of the model, its drawbacks and potential, so that they are able to understand and thus defend the results of a modelling tool in a political process. Other option is to have an interface team (e.g. JRC) between the policy makers and modellers.

In the case of the EURURALIS, SENSOR, and the SEAMLESS projects, an easy-to-use DSS that allows users to browse through already modelled was developed. Such system is easy-to-use by users with a wide range of technical abilities and experience. Nevertheless, it is important to highlight that experiences gained in these projects suggest that even for an easy-to-use DSS, some training is required, mainly regarding the interpretation of the results that are obtained. Also, the flexibility and interactivity of this type of interface tool is very limited as the policy-makers can only analysed a pre-established set of scenarios and policy questions. This issue was also highlighted and discussed during the workshop organised in the framework of this study in June 2008 (see Appendix 3).

6.2.2. Simulation time

Model runs can take from a few minutes to several days depending on the scenarios and the questions to be analysed. Nevertheless, to create a new run (i.e. adjust values, add new demands, create new scenarios) can take between minutes to several weeks depending on how thoroughly the new scenario are defined.

In the case of easy-to-use DSS that allows users to browse through a wide set of simulation results that have obtained from a previously run modelling system, the simulation of the different scenarios usually takes few seconds as the calculations are based on a database of results resulting from the modelling framework pre-simulation.

6.2.3. Linkage potential

Linkage problems between models often arise, particularly when integrating existing models that have been created by different modelling teams. This has been an issue widely discussed in the case of the SENSOR SIAT, where various sectoral models are integrated.

6.3. TECHNICAL REQUIREMENTS

The actual modelling tools usually have high computational and data demands. The computational demands of the easy to use and simplified DSS tools (such as the EURURALIS 2.00 and the SENSOR SIAT), on the other hand, are easily met. Such modelling option can usually be delivered in CD or available in internet for download. They are compatible with Windows platforms and the size of the data files is usually below 800MB.

Another important aspect to take into account is if models or modelling frameworks are open source or whether the source is restricted, limiting the possibilities for other teams within the Commission to use the model.

6.4. GENERAL REMARKS

Many different existing modelling tools do only cover certain levels needed within the specific assessment they have been designed to address and they do not link the micro (field, municipality, farm, city) and the macro (sector or market) levels. Nevertheless, many different policy questions cannot be solved at micro or macro levels only. Therefore, a crucial remaining challenge is to develop multi-scale methods that allow improving and performing analysis at micro and macro scales and that acknowledges that different driving forces are important at different scales. In this regard, one of the main barriers is to obtain data on specific regional economy and policies, which would be useful to establish land claims allocation between different sectors at the regional or local level. Most modelling frameworks and modelling tools use a top down approach. SEAMLESS IF has succeeded in dealing with different scales in detail (from the farm system to the European level) with a bottom-up approach.

As indicated before, many different modelling tools have mainly focused on either the biophysical, economic or social disciplines and in general, the degree of quantification of the potential impacts of land-use changes is observed to be imbalanced. One of the main focuses of the SENSOR project has been the development of an indicator framework that could cover social environmental and economic impacts.

In general, social aspects and drivers such as quality of life, formal and informal social rules, and people's preferences and behaviour (which can have a very relevant influence on land-use changes particularly at the local and regional levels) are generally not well represented in most modelling tools.

Many modelling tools are case specific, which limit their re-utilisation in different policy questions than the ones addressed and their timely availability for application to rising policy issues. Moreover, the different components of existing modelling tools are rarely re-usable outside the environment for which they were developed.

One of the main difficulties is the linkage of the different components or models. In general, when the policy questions to be addressed require integration of research in different disciplines, a multinational team from different research institutions have usually been involved. Nevertheless, having different research groups or teams involved in the development of each of the models that are to be linked can present some difficulties regarding transparency and harmonisation of approaches.

7. OPTIONS FOR A POSSIBLE LAND-USE POLICY MODEL

Various options are possible to develop a land-use modelling framework for assessing environmental impacts of land-use changes. The suitability of a particular option depends on the foreseen applications, modelling architecture, and related operational issues. As explained earlier, while in the beginning of the study the main objective was that would be able to address different issues related to land-use changes in Europe, the study has evolved from defining the scope of a specific future integrated assessment modelling framework to a review of existing modelling tools and their applicability potential in evaluating environmental impacts related to land-use changes. After presenting different existing modelling tools in Europe in the preceding sections, this section analyses different possible options for a future EU-wise land-use modelling tool.

7.1. FORESEEN APPLICATIONS

The type of application strongly determines the set-up of the land-use modelling framework. An initial distinction can be made by the foreseen *application domain*. One can typically distinguish between **sector-specific applications** and **integrated applications** that consider all land-use functions simultaneously. For sector-specific applications, for example looking at the prospects of agriculture in Europe, a single dedicated model (e.g. CAPRI) usually suffices. However, integrated applications, for example, the analysis of the impacts of climate change, may call for a modelling approach that combines the output of different sector-specific models into one coherent framework so as to provide a plausible future outlook.

Different *application types* were presented in Section 5.1. For the selection of an appropriate modelling framework, it is important to identify the phase of the planning process (preparation, development, or evaluation) during which it will be applied. In the preparation phase, models that can perform trend extrapolations or scenario analyses are needed, whereas in the development phase impact assessments or optimisation studies are often more appropriate.

Table 5 presents different policy-relevant issues that could be analysed in the future by the Commission in the context of policy evaluation, the drivers and impacts that should be taken into account, and possible modelling components that would be required to address each of these issues. Furthermore, the Table 5 also lists relevant modelling experiences for each case.

Table 5 – Possible modelling tools for assessing different policy issues

Issue	Drivers	Potential impacts/indicators to be assessed through modelling	Modelling components required	Examples of relevant research
Water scarcity	- Precipitation patterns - Economic growth - Population dynamics - Evolution of water demand for different sectors - Agricultural production - Price of water - Physical conditions - Technology - Water saving policies	- Areas facing possible water management problems due to water shortage - Increase or decrease of areas with significant reduction of water availability - Erosion - Desertification - Irrigation water usage - Amount of water from outside the region - Water prices - Amount of water resources available in aquifers	- Global economic model (e.g. LEITAP/GTAP, NEMESIS) - Hydrological model (e.g. SWIM[29], VIC model[30]) - Climate model (e.g. STAR)[31] - Tourism model (e.g. B&B developed under the SENSOR project) - Agriculture model (e.g. CAPRI) - Forestry model (e.g. EFISCEN) - Land-use model (e.g. CLUE, Land Use Scanner, METRONAMICA)	- The Land-use Scanner has been applied in the Netherlands to assess water shortage (Dekkers and Koomen, 2007) - The programme Global Change in the Hydrological Cycle (GLOWA)[32] evaluated the impact of climate and social change on the total catchment areas of the Elbe river and Rhine/Meuse system considering global environmental and socio-economic conditions

[29] Soil water Infiltration Model (SWIM) was developed by *Potsdam Institute for Climate Impact Research (PIK)*. More information available at: http://www.scisoftware.com/products/swim_details/swim_details.html

[30] Variable Infiltration Capacity (VIC) Macroscale Hydrologic Model. More information available at: http://www.hydro.washington.edu/Lettenmaier/Models/VIC/VIChome.html

[31] STAtistical Regional model (STAR) was developed by *Potsdam Institute for Climate Impact Research* to minimise the inaccuracy of regional results of climate simulations from global models.

[32] More information available at: http://www.glowa-elbe.de/german/index-en.htm

Issue	Drivers	Potential impacts/indicators to be assessed through modelling	Modelling components required	Examples of relevant research
Floods	- River discharge - Precipitation patterns - Increase of impermeable surfaces - Land-use patterns - Physical conditions	- Floods probability, - Flood damage, - Potential casualties - Costs	- Demographic model (e.g. PHOENIX) - Global economic model (e.g. LEITAP/GTAP, NEMESIS) - Hydrological model (e.g. SWIM, VIC model) - Climate model (e.g. STAR) - Land-use model (e.g. CLUE, Land Use Scanner, METRONAMICA) - Global environmental model (IMAGE)	- The Land-use Scanner has been applied to assess flood risk in the Netherlands. - The MOLAND model, integrated with other models, has provided information to prevent and mitigate the effects of extreme weather driven events such as flood and forest fires
Impact of changes in agriculture	- Agricultural production - Population growth - Agricultural and nature conservation policies - Market prices - Climatic conditions	- N-surplus - nitrate balance - Soil biodiversity - Visual landscapes changes - Competition for land by biofuels and agriculture - Erosion - Decline in organic matter - Soil contamination (local and diffuse) - Soil sealing - Agricultural income (GDP/capita) - Employment - Crop diversity - Carbon sequestration - Irrigation water usage - Land abandonment	- Agriculture model (e.g. CAPRI) - Forestry model (e.g. EFISCEN) - Global economic model (e.g. LEITAP/GTAP, NEMESIS) - Climate model (e.g. STAR) - Land-use model (e.g. CLUE, Land Use Scanner, METRONAMICA) - Demographic model (e.g. PHOENIX) - Pollution model (N and GHG emissions from agriculture such as e.g. MITERRA) - Soil erosion model (e.g. PESERA model) - Global environmental model (IMAGE)	- The EURURALIS modelling framework assess different aspects of agricultural land-use change including soil related indicators such as carbon sequestration, erosion risk and N-surplus - SEAMLESS-IF has been applied and tested in two Test Cases: CAP reforms and trade liberalisations as a consequence of WTO negotiations. - Scenario study SCENAR 2020, uses different simulation models - The MITERRA-Europe model, developed for the European Commission (DG Environment), assesses N emissions from agriculture at regional, country, and EU-27 levels.
Soil	- Agriculture production - Spatial and nature policies - Urbanisation patterns - Economic growth	- Erosion rate - Decline in organic matter - Soil contamination (local and diffuse) - Soil sealing - Soil compaction - Carbon sequestration	- Agriculture model (e.g. CAPRI) - Forestry model (e.g. EFISCEN) - Global economic model (e.g. LEITAP/GTAP, NEMESIS) - Land-use model (e.g. CLUE, Land Use Scanner, METRONAMICA) - Demographic model (e.g. PHOENIX)	The Pan-European Soil Erosion Risk Assessment - PESERA - uses a process-based and spatially distributed model to quantify soil erosion by water and assess its risk across Europe. The conceptual basis of the PESERA model can also be extended to include estimates of tillage and wind erosion.

Issue	Drivers	Potential impacts/indicators to be assessed through modelling	Modelling components required	Examples of relevant research
	- Population dynamics - Increase of impermeabilisation - Land intensification and marginalization	- Floods and landslides - Soil salinity - Decline in soil biodiversity	- Soil erosion model (e.g. PESERA model) - Global environmental model (IMAGE)	The model is intended as a regional diagnostic tool, replacing comparable existing methods, such as the Universal Soil Loss Equation (USLE), which are less suitable for European conditions and lack compatibility with higher resolution models.
Biodiversity	- Spatial and nature conservation policies - Climatic conditions - Economic development - Population dynamics	- Changes in the surface of protected areas - Area of sensitivity areas - Number of endangered species (Red List) - Natural vegetation change - Landscape fragmentation - Cost of biodiversity loss - Loss of recreational areas	- Hydrological model (e.g. SWIM[33], VIC model[34]) - Climate model (e.g. STAR) - Tourism model - Agriculture model (e.g. CAPRI) - Forestry model (e.g. EFISCEN) - Global economic model (e.g. LEITAP/GTAP, NEMESIS) - Transport model (e.g. TRANSTOOLS, , ASTRA, TIGRIS XL, SCENES-TREMOVE) Land-use model (e.g. CLUE, Land Use Scanner, METRONAMICA) - Demographic model (e.g. PHOENIX) - Impacts on the biosphere model (e.g. GLOBIO)	The GLOBIO model estimates threats to biodiversity using a multiple-stressor based index methodology. It uses buffer zones/infrastructure density to estimate the human pressure on ecosystems.
Impacts of transportation networks	- Economic growth - Migration - Demography - Housing market - Spatial planning	- Accessibility - Congestion - Air pollution - Fragmentation or loss of open spaces - Soil sealing - Water run-off	- Global economic model (e.g. LEITAP/GTAP, NEMESIS) - Transport model (e.g. TRANSTOOLS, , ASTRA, TIGRIS XL, SCENES-TREMOVE) - Agriculture model (e.g. CAPRI) - Forestry model (e.g. EFISCEN) - Tourism model - Land-use model (e.g. CLUE, Land Use	- The ASTRA model allows for the assessment of transport strategies regarding air pollution and greenhouse gas emissions. - TIGRIS XL transport interaction models has been applied in interaction with the Land Use Scanner in a major scenario study 'The Netherlands in the Future' conducted by

[33] Soil water Infiltration Model (SWIM) was developed by *Potsdam Institute for Climate Impact Research (PIK).* More information available at: http://www.scisoftware.com/products/swim_details/swim_details.html

[34] Variable Infiltration Capacity (VIC) Macroscale Hydrologic Model. More information available at: http://www.hydro.washington.edu/Lettenmaier/Models/VIC/VIChome.html

Issue	Drivers	Potential impacts/indicators to be assessed through modelling	Modelling components required	Examples of relevant research
		- Erosion	Scanner, METRONAMICA) - Demographic model (e.g. PHOENIX)	the Environmental Assessment Agency in the Netherlands. - The model SCENES is used by the European Commission in the framework of different research projects (EXPEDITE, MC-ICAM, IASON, TIPMAC, SPECTRUM). The model has also been used in various European studies on transport issues.
Climate change	- Greenhouse gas emissions	- Likely use at a specific location in the future under different climate conditions. - Land-use impacts of adaptation options, e.g. green infrastructure for ecosystems resilience, water retention, flood prevention - Desertification - Crop diversity - Crop change	- Hydrological model (e.g. SWIM[35], VIC model[36]) - Climate model (e.g. STAR) - Air pollution and emission models (e.g. RAINS, Eco-Sense) - Agriculture model (e.g. CAPRI) - Forestry model (e.g. EFISCEN) - Global economic model (e.g. LEITAP/GTAP, NEMESIS) - Transport model (e.g. TRANSTOOLS, , ASTRA, TIGRIS XL, SCENES-TREMOVE) - Land-use model (e.g. CLUE, Land Use Scanner, METRONAMICA) - Demographic model (e.g. PHOENIX)	Socio-economic and climatic dimension of different scenarios are used in the Dutch LANDS project. The selected scenarios are fed into the *Land-use Scanner* model that simulates future land-use patterns.
Urban Sprawl	- Housing market - Labour market - Demography - Economic growth - Migration - Transport	- Fragmentation or loss of open spaces - Increase distance from residence to work - Air pollution - Soil sealing	- Global economic model (e.g. LEITAP/GTAP, NEMESIS) - Transport model (e.g. TRANSTOOLS, , ASTRA, TIGRIS XL, SCENES-TREMOVE) - Agriculture model (e.g. CAPRI) - Forestry model (e.g. EFISCEN) - Land-use model (e.g. CLUE, Land Use	

[35] Soil water Infiltration Model (SWIM) was developed by the *Potsdam Institute for Climate Impact Research (PIK)*. More information available at: http://www.scisoftware.com/products/swim_details/swim_details.html

[36] Variable Infiltration Capacity (VIC) Macroscale Hydrologic Model. More information available at: http://www.hydro.washington.edu/Lettenmaier/Models/VIC/VIChome.html

Issue	Drivers	Potential impacts/indicators to be assessed through modelling	Modelling components required	Examples of relevant research
	development	- Recreational areas	Scanner, METRONAMICA) - Air pollution and emission models (e.g. RAINS, Eco-Sense) - Demographic model (e.g. PHOENIX)	

The characteristics of the modelling tool will depend on the policy question that is being addressed. If only specific issues need to be taken into account, such as the areas cropped, the nutrient balances (N, P, K), or the emissions (ammonia, methane and N_2O) resulting from agricultural policies in the CAP at the regional level, using agriculture sectoral models such as CAPRI (results in NUTS2 plus 1x1 km grid) should be sufficient (See Appendix 8 which presents different sectoral models and the outputs they can provide). Nevertheless, if the objective is to perform an integrated assessment of N emissions from agriculture at regional, country, and EU-27 levels, it would be necessary to couple the agricultural sectoral model with another model (e.g. air pollution model) to estimate emission of NH_3 and NOx such as RAINS. Such approach has been adopted by the MITERRA-Europe project.

During the workshop organised in the framework of this study in June 2008 (see Appendix 3), it was highlighted that land-use modelling is by nature a multi sector activity as different sectors compete for scarce land resources, and therefore, it would be important to recognise this multi-sector nature when defining the application domain. Hence, and in order to better meet current and future analytical needs, it is recommended to use an integrated application that takes into account the different trade-offs between sectors. Indeed, the most suitable EU land-use modelling tool would need to allow the inclusion of different modelling components related to the drivers of change, the land allocation, and impact indicator models depending on the specific issues to be analysed.

It can also be observed in the table above that certain core components are always required independently of the issue being addressed. One of the most important elements of the future integrated land-use modelling framework will be the land-use model, linking sectoral models and indicators and connecting European scale analysis to the level of environmental impacts. As explained in section 5.3.2, there is a wide range of possible land-use models that could be used such as the CLUE, Land Use Scanner and the METRONAMICA, which have been already applied in the context of different European projects (these and other land-use models are further described in Appendix 9).

In addition, global economic models such as GTAP or NEMESIS can be used to define global demand for different types of land-use. The need of using macro-economic and demographic models was also agreed during the workshop organised in the framework of this scoping study (see Appendix 3). Regional sectoral models such as CAPRI or EFISCEN or the demographic model PHOENIX would be necessary to the demands and restrictions for land use.

This integrated application should be able to address the three domains of sustainable land use: social, environment and economy. In particular, and directly in relation to land, this application would be able to provide results (at the European, national, regional levels) on:

- projected land use (including developments of the surface of different agricultural sectors, the forestry sector, urban areas and natural areas)
- simulated land-cover characteristics (e.g. carbon sequestration characteristics)
- accessibility
- land prices
- agricultural abandonment and intensification
- fragmentation or loss of open space
- changes in land diversity
- soil sealing
- land use suitability
- emissions (ammonia, methane and N_2O) to land

For example, if the CLUE-s model as land-use allocation model is used, the resolution of the output could be of 1 km^2.

If coupled with other models, the integrated framework will be able to provide information about other and more complex indicators such as erosion (if linked for example with the PESERA model), changes in the hydrologic balance and water quality (if linked with, for example, the VIC or the SWIM models), greenhouse gases and Nitrogen dynamics (if linked with air pollution models such as RAINS), etc.

7.2. MODEL STRUCTURE

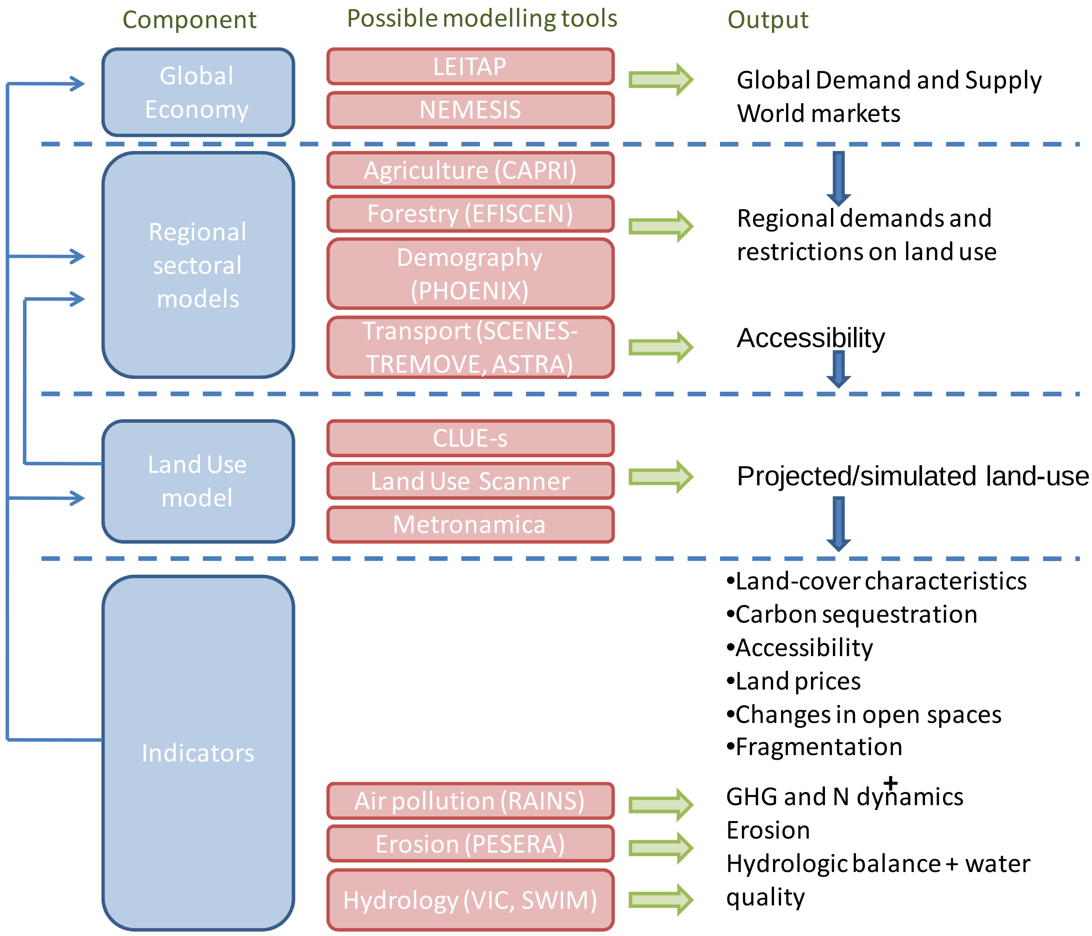
7.2.1. BASIC ARCHITECTURE

Concerning the basic modelling architecture, two main options exist. Models can be developed as **stand-alone entities that replace existing components** (such as SEAMLESS) or as **integration framework that use existing components** (such as Eururalis). The former are typically complex, data-demanding models that take a lot effort to develop, but offer the possibility to deliver coherent results. The latter are typically more open, simple models that are more easily adapted to new applications, but run the risk of producing less coherent results. It is important to note that in these applications the actual land-use allocation model is only one element in a chain of different models that produce meaningful results for policy makers.

It was generally agreed during the workshop that for the basic modelling architecture, the use of a component-based integrated tool seemed to be most appropriate; with different sector-specific models (representing different processes at different hierarchical levels) constituting discrete and reusable components that could be integrated in the modelling framework depending of the policy questions to be addressed. The specific components to be added in the modelling framework and the potential linkage issues will be conditioned by the policy questions. Once the components are decided, they will be implemented in the software structure, which would allow linking the input and output of models through scripts.

In accordance with the option proposed in section 7.1, the following figure illustrates the structure that could be considered.

Figure 10 – Possible model components



In order to plug the different components together, the DMS software, explained in section 5.3.1 could be used. The main advantage of using this framework is that, in contrast to many other frameworks, DMS is available as an open source product (GNU-GPL) and has already been successfully applied in various projects linking land use models, databases and indicator models.

7.2.2. USABILITY

As regards usability one can distinguish between a **user-friendly system** that is open to many (no-expert) users and **specialist's tools** that is operated by a few trained modellers. Knowing the complex nature of land-use simulations one can argue however, that very few non-expert users will be able to understand the implications of all possible choices in the simulation process. Land-use models therefore remain at large a specialist's tool. In addition, however, a user-friendly interface is sometimes created that allows policymakers to browse through sets of pre-programmed simulation results. The main characteristics of these different types of tools are listed in the table below.

Table 6 - Technical and human requirements depending on the modelling approach

Type of tool	Potential users	Technical requirements	Human requirements
Specialist's tool	- Specialised Scientists - Specialised consultants - Trained administrators and policy makers	- High computational demands - High data demands - Regular update	- Multiple expertise needed - Requires land-use modelling experience - Programming language knowledge required - Calibration requires expertise
User-friendly DSS	- Administrators - Policy makers	- Low computational demands - It does not require for specific software or it is easy to obtain (e.g. Java)	- Does not require land-use modelling experience - Easily to use by users with a wide range of technical abilities and experience.

7.3. OPERATIONAL ISSUES

Last but not least, a number of operational issues have to be dealt with related to model output and model characteristics. Output of a Land-use model is typically delivered in the form of tables and maps. To provide sensible results for policymaker, additional impact assessment tools may be applied. Such tools may consist of the straightforward application of a set of if-then relations, but may also consist of more elaborate models as is the case in hydrological models that simulate groundwater-recharge or river run-off based on land-use maps. Additionally land-use maps can be visualised as 2 or 3-dimensional maps in, for example, Google Earth.

The main *model characteristics* partially follow the choices made in relation to the above-mentioned criteria. Important elements related to representation of land use are: spatial and thematic resolution and geographical extent. In relation to the simulation of future land use, choices will have to be made related to the time horizon, the regional divisions that will be applied to store and display specific types of information, the degree of dynamics that are preferred and the main allocation principle. Other technical considerations relate to the reliability, preferred performance, degree of interoperability (ease of information exchange) and flexibility (ability to adjust to new applications).

8. ROADMAP FOR FURTHER DEVELOPMENT

In order to be able to define an appropriate EU modelling framework, it is necessary to identify the end-user and the minimum requirements taking into consideration the current analytical needs, the technical and human limitations, and the best way to present the results in a comprehensive and useful manner. Indeed, the development of a system requires close contact with a real user group to prevent it from becoming an academic exercise. It is important to take into consideration that the model needed today may be completely different compared to one for tomorrow, therefore, it is important that the models are flexible and that the required data can be updated consequently. The current proposal attempts to summarise the current ideas for an EC land-use modelling framework, discussing the various options presented in the previous section.

8.1. FORESEEN APPLICATIONS

Based on previous discussions with the different units of the European Commission and other EU institutions, a synthesis of the analytical needs for different EU policies and programmes is summarised in Appendix 11. This helps to understand the key aspects that could be addressed/ analysed in a land-use modelling framework in order to meet current and future needs and what would be the modelling requirements. The identified issues have also been commented in section 7.1 in terms of drivers and indicators that should be taken into account in each case.

One important aspect to be taken into account is that a potential failure for a modelling framework is a mismatch between the modelling and the policy context. The modelling should be tailored to the policy options that are defined and the output (in the form of indicators/information) it needs to produce for the evaluation.

8.1.1. APPLICATION DOMAIN

In general, **integrated** modelling frameworks play a key role in any planning support system as their constituting (sub-) models or components can cover, at the least in part, different (sub-) domains that are relevant to the different policy questions. Furthermore, they can potentially include the many complex linkages between the (sub-) domains. Thus, they provide immediate access to a wide and operational knowledge of the policy domain in a broad context. According to the EC analytical needs presented in Appendix 11, an integrated application will be most suitable. Such a model will use the output of different sector-specific models and simulate different types of land use simultaneously. Which sector-specific models are to be included in the modelling framework depends on the analytical needs of the anticipated application. It is likely that these include specified models related to: hydrology; climate; tourism; agriculture; forestry; economics; and transport.

8.1.2. Application type

The main application type of the modelling tool to be developed will be ex-ante policy assessment and planning during the **development** phase. The framework for the production of such a modelling tool will therefore be related with the approach to impact assessment in the EC and the key questions to be answered in relation with such policy initiatives. The modelling tool will facilitate assessing proposed policy options by comparing a baseline scenario with other policy scenarios differing from the proposed and accepted policies. The modelling framework should thus be able to flexibly include many different types of scenarios and spatially explicit policy options. The possibility to explore different scenarios to better understand possible future developments will also be useful in the **preparation** phase to help recognise specific spatial problems and draft different policy alternatives.

8.2. MODEL STRUCTURE

8.2.1. Basic architecture

For the basic modelling architecture, the use of a **component-based** model seems to be most appropriate. This will optimise the memory and computing needs of the model in real-time. The different sector-specific models representing different processes at different hierarchical levels will constitute discrete and reusable components that can be integrated in the modelling framework depending of the policy questions to be addressed. A component-oriented software will have to be used (developed) to allow the proposed modular modelling. The software infrastructure will allow for the use and linkage of the necessary components to underpin the integrated assessment. Other components, besides the sector-specific models, would be the databases and the indicator calculation modules, for example.

During the workshop organised in the framework of this study in June 2008 (Appendix 3), participants generally agreed on the fact that the modelling framework should use existing models that have been validated and applied for addressing policy questions already in Europe. As many sector-specific models are already used in different EC-projects the main focus of the new modelling framework should initially be on developing an integration framework for these components. This can be a quite challenging due to the linkage of models can be complex due to problems resulting from overlap, the level of aggregation of the information, limiting policy responsiveness, etc. In some cases, it might be preferable to select or build models and components following a general system design than to start linking existing components[37].

The land-use modelling framework is aimed to support European policy-makers to understand the potential social, economic and environmental impacts of land-use changes resulting from different policy actions. Potential users of such a tool include: administrators; policy makers; scientists; and consultants.

The proposed model will have to be run by trained modellers given the complexity of the expertise required to integrate and calibrate the different components of the model. Therefore, it would consist of a **specialist's tools**. The Commission possesses a limited amount of personnel with special technical expertises to use and calibrate models. Therefore, it can be assumed that in most cases it will be necessary to externalise this service. The potential final user of the EU land-use modelling framework and the usefulness of user-friendly DSS were discussed during the workshop. It was generally agreed, based on the experience of previous European projects that it is very time consuming and complex to develop such tool and that even with a very simplified version, some kind of assistance from experts was necessary. If necessary, a **user-friendly system** could be developed for non-experts based on the pre-run results and for certain applications, similar to the case of EURURALIS. This user-friendly tool can be used for communication purposes with non-expert stakeholders and support policy discussion but it should not be used considered as a real decision support tool. Such a tool will have to run on a personal computer and should not require modelling knowledge. In the case of such an easy-to-use DSS, it is important that the modelling tool has clearly arranged operating panels adapted to the needs of the end users at the Commission (i.e. policy officers from different DGs). This should be an easy to use analytical system, enabling policy makers to interactively enter policy options in order estimate their related potential land-use scenarios (under a specific set of natural, social and economic conditions) and to assess their potential impacts.

As it has been indicated in previous sections, and agreed during the workshop, there seems to be an important lack of awareness about the current state of modelling tools and their potential amongst policy-makers and about the policy analytical needs amongst scientist and model developers. One of the main issues to be addressed to improve this gap is communication. For example, insufficient attention is often given to the inventory of the questions of the policy makers due to the sometimes inward-looking attitude of scientists and modellers. On the other hand, decision support systems are not adequately used by the stakeholders they were developed for. Policy-makers should be involved in the pre-modelling (to define the policy questions to be addressed, the indicators and the policy scenarios) and post-modelling phase (in order to interpret and apply the results in policy-making). Furthermore, it would be advisable

[37] Workshop discussion. See appendix 3.

that relevant Commission officers are consulted during all phases of the development of the modelling framework.

In any case, the modelling framework should be 'transparent' for end user (each methodological step has to be traceable and concise in its illustrations and transparent regarding assessment and data quality).

8.3. OPERATIONAL ISSUES

8.3.1. LAND-USE MODEL INPUT

The integrated EU modelling framework should take into consideration as many different land-use classes as possible, using existing base data on land cover (CLC/CORINE). Appendix 4 provides examples of the land-use/cover categories that are already in use by some existing modelling frameworks. The possible land-cover classes could be, for example, the following: Built-up area, arable land (non-irrigated), pasture, (semi-) natural vegetation, inland wetlands, glaciers and snow, irrigated arable land, recently abandoned arable land, permanent crops, biofuel cultivation, forest, sparsely vegetated areas, beaches, dunes and sends, salines, water and coastal flats, heather and moorlands, recently abandoned pasture.

Environmental data for specific policy cases will be derived from discussions with the Commission, from adapting current policy data or trough contacting pan European research institutes such as JRC that collect European wide data.

8.3.2. LAND-USE MODEL OUTPUT

The main output of the modelling tool will be in the form of tables and maps, including at least the following:

- Land-use maps of base year and final simulation year
- Land-use change maps
- Indicator maps showing specific thematic impacts (e.g. increase of built-up areas in floodplains)
- Tables presenting national and regional indicator values
- Additionally, dedicated tools and models can be run based on the simulation outcomes to obtain specific environmental impacts.

It is useful if the indicator values can easily be aggregated at different thematic and spatial levels and sustainability themes to get quick scan answers at different levels. In addition, it can be advantageous to display baseline values, thresholds, and targets to facilitate comparison.

8.3.3. MODEL CHARACTERISTICS

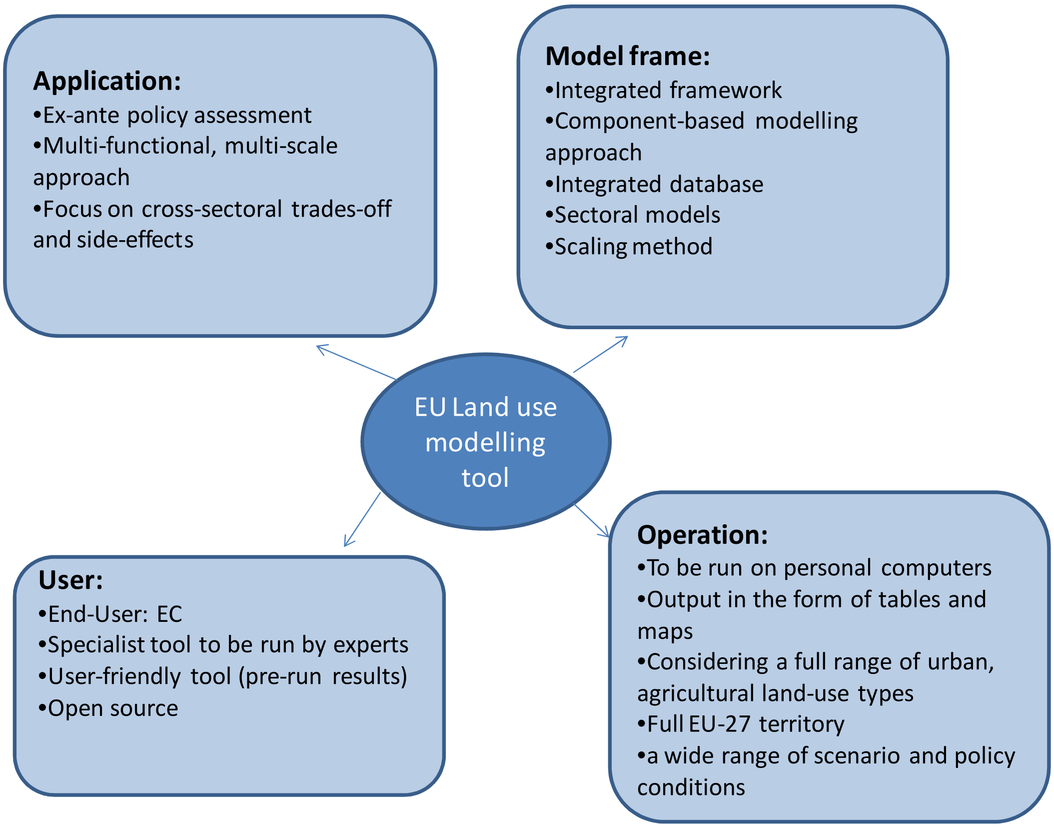
The exact definition of the model characteristics depends on the specifics on of the intended application. As an initial guideline for a generic land-use modelling framework a number of model characteristics is proposed in the table below.

Table 7 – Main characteristics of the proposed land-use modelling framework

Model characteristic	**Proposal**
spatial resolution	preferably 500m grid cells
thematic resolution	full range of urban, agricultural land-use types based on CORINE simulating a maximum of 15 types per application
geographical extent	full EU-27 territory
time horizon	2040/2050 (EU policy horizon)
degree of dynamics	preferably time steps taking into consideration typical policy evolution (e.g. 5-7 years)
allocation principle	no preference, as long as notions of proximity and economic processes can be included
regional divisions for aggregation	Nuts 1/Nuts 3
reliability	an extensive validation on the 1990-2000 should be presented together with the model
performance	to be run on a single personal computer
interoperability	open source
flexibility	maximum flexibility to incorporate a wide range of scenario and policy conditions

The figure below summarises the main characteristics of the proposed land-use modelling framework for the EC

Figure 11 - Main characteristics of the proposed land-use modelling framework



8.4. RESOURCE ESTIMATION

Based on the previously described characteristics an initial estimate is made of the resources that are needed to develop and maintain the land-use modelling framework. A distinction is made between the following types of resources:

- Input data needs, source of such data and data reliability aspects
- Development time
- Maintenance time
- Technical expertise required for operating the framework

The starting point for any model of European model of land use is the CORINE database. This datasets has several drawbacks relating to, for example, cross-country differences in classification and a relatively large the minimum mapping size, but it remains the only available pan-European land-use data set. It is furthermore freely available, thus putting no constraint on the resources. Other relevant spatial datasets relating to for example: accessibility, the physical surroundings (soil type, groundwater tables, slope, altitude) and, especially, (sub)national policy maps are much more difficult to obtain. Ample time should be reserved to collect and implement these data sets. It is important to note that a well-calibrated model should have the possibility to distinguish different driving forces for different European regions and also weigh these differently per country or region.

Coupling existing model components seems to be the most efficient strategy to create a modelling framework that remains flexible and incorporates the best available knowledge on sector-specific developments and impacts. Substantial time should in this case be reserved for creating smooth interfaces between these models and for safeguarding the internal consistency of the select model components.

Through creating a relatively light coupling of existing model components, maintenance of the individual components remains possible at the institutes that possess the best knowledge on recent developments. This distributed approach has the advantage of limiting the resources needed in updating the building blocks of the modelling framework. Maintenance time remains necessary, however, as the interfaces with the different components may need to be updated.

To actually operate the envisaged modelling framework, the end users need to be trained in handling the model and, more importantly, in understanding the consequences of changing model parameters and assessing the value of the obtained results. A two-day training workshop for anticipated end-users seems a minimal prerequisite here.

This page is left intentionally blank.

9. CONCLUSIONS

Following are some of the recommendations developed in light of the discussions during the workshop on the possible options for a future modelling framework and the presentation of the proposed roadmap for the development of such modelling tool.

Globally, a generic framework is required where existing models ("light" or "complex" from a computational point of view) could be coupled (integrated, component-based modelling tool) depending on the specific questions to be addressed. The models to be used should have been validated previously and with concrete application in real cases and therefore, it is advisable to use, and adapt if necessary, existing modelling tools. Indeed, the future EU modelling framework should take into account previous relevant modelling experiences gained through different EU projects such as Eururalis, SENSOR, NITRO-EUROPE, FARO, EFORWOOD, PLUREL and RUFUS projects, and specific tools developed there.

It is also important to define first the list of the most crucial policy questions that have to be addressed and what aspects need to be explored for each of these questions. Subsequently, it would be possible to define more precisely how to analyse these questions though the modelling tool. To begin with, one could focus on two or three policy questions to start and then adapt the modelling framework to further policy questions.

Despite the fact that the proposed modelling framework would have to be run by trained modellers (because of the complexity of the expertise required to integrate and calibrate different components), the need for an active involvement of policy makers is necessary along the whole process of development of the modelling framework.

There are existing tools that could be used in the future modelling framework, nevertheless certain gaps will have to be addressed in the near future. Some gaps that may require further research are following:

- More research is required to improve our knowledge about the relationship between land-use changes and the resulting environmental impacts. Also more research is required to develop the methodology for assessing the resulting environmental impacts.
- Social and economic impacts are not addressed to an appropriated detail in most existing modelling tools. Further research would also investigate better ways to accommodate behaviour patterns and human preferences in modelling tools, which cause important impacts on land-use changes. Appropriate indicators should be developed in this regard.

- The link between changes in land use and their impacts into landscape is not very well known. This is one example where the scaling issues becomes important.
- Awareness raising is necessary about the current state of modelling tools, their potential, policy analytical needs, and the needed development among policy-makers and also scientist.

10. REFERENCES

Borsboom-van Beurden, J (2008) Presentation during the workshop on "Modelling of EU land-use choices and environmental impacts " held the 26 June 2008 in Brussels

Borsboom-van Beurden, J., Bakema, A. and Tijbosch, H. (2007) A land-use modelling system for environmental impact assessment. Chapter 16 in: Koomen, E., Stillwell, J., Bakema, A. and Scholten, H.J. (eds.) Modelling land-use change; progress and applications, Springer, Dordrecht, pp. 281-296.

Eickhout, B. and A.G. Prins (2008). Eururalis 2.0 *Technical background and indicator documentation*. Wageningen UR and Netherlands Environmental Assessment Agency (MNP) Bilthoven, The Netherlands

Costanza, R. and A. Voinov (2003) Introduction: spatially explicit landscape simulation models. Pp. 3-20 in: R. Costanza and A. Voinov (eds). L*andscape Simulation Modeling: A Spatially Explicit, Dynamic Approach*. Springer, New York.

Dale, V.H. (1997) The relationship between land-use change and climate change, *Ecological Applications*, 7 (3): 753–769.

De Sherbinin, A. (2002) *A CIESIN Thematic Guide to Land Land-Use and Land Land-Cover Change (LUCC)*. Center for International Earth Science Information Network (CIESIN) Columbia University Palisades, NY, USA. Available online at: http://sedac.ciesin.columbia.edu/guides/lu/CIESIN_LUCC_TG.pdf.

Dekkers, J. and Koomen, E. (2007) Land-use simulation for water management; Application of the Land-use Scanner in two large-scale scenario studies. Chapter 20 in Koomen, E., Stillwell, J., Bakema, A. and Scholten, H.J. (eds.) *Modelling land-use change; progress and applications*, Springer, Dordrecht, pp. 355-373.

EEA (2006a) *Urban sprawl in Europe -The ignored change.* EEA Report n°10/2006. EEA and European Commission/Joint Research Centre, Copenhagen. 60pp. Available online at: http://reports.eea.europa.eu/eea_report_2006_10/en

EEA (2006b) *Land accounts for Europe 1990–2000 - Towards integrated land and ecosystem accounting*. EEA report n°11/2006. EEA, Copenhagen. 112pp. Available online at:

EEA (2007) *Land-use scenarios for Europe: qualitative and quantitative analysis on a European scale.* EEA Technical Report n°9/2007. EEA, Copenhagen. 78 pp. Available online at: http://reports.eea.europa.eu/technical_report_2007_9/en

Engelen G., van Delden H., and Luja P., (2007) Integration of multi-scale dynamic spatial models of socio-economic and physical processes for river basin management. Environmental Modelling & Software 22 (2007) 223e238

Eppink, F.V., Rietveld, P., van den Bergh, J.C.J.M., Vermaat, J.E., Wassen, M.J. and Hilferink, M. (2008) Internalising the costs of fragmentation and nutrient deposition in spatial planning: Extending a decision support tool for the Netherlands. Land Use Policy 25(4): 563-578.

European Commission (2007) *Scenar 2020 – Scenario study on agriculture and the rural world*., Luxembourg, 236 pp. Available online at: http://ec.europa.eu/agriculture/agrista/2006/scenar2020/final_report/scenar2020final.pdf

European Comission (2005) Impact Assessment Guidelines. SEC(2005) 791. June 2005. Available online at: http://ec.europa.eu/governance/impact/docs/key_docs/sec_2005_0791_en.pdf

Foley, J.A., DeFries, R., Asner, G.P., Barford, C. and Bonan, G. Carpenter, S.R., Chapin, F.S., Coe, M.T., Daily, G.C., Gibbs, H.K., Helkowski, J.K., Holloway, T., Howard, E.A., Kucharik, C.J., Monfreda, C., Patz, J.A., Prentice, C., Ramankutty, N. Snyder, P.K. (2005) *Global Consequences of Land-use, Science*, 309(5734), 570-574.

Genovese, E. (2006) A methodological approach to land-use-based flood damage assessment in urban areas: Prague case study. DG-JRC, Ispra. EUR 22497 EN

Geurs, K. and Van Wee, B. (2006) Ex-post evaluation of thirty years of compact urban development in the Netherlands. Urban Studies 43(1): 139-160.

GLP (2005) *Global Land Project; Science Plan and Implementation Strategy*. IGBP Report No. 53/IHDP Report No. 19. IGBP Secretariat, Stockholm. 64pp.

Hartje, V., Klaphake, A., Grossmann, M., Mutafoglu, K., Borgwardt, J., Blazejczak, J., Gornig, M., Ansmann, T., Koomen, E. and Dekkers J. (2005) Regional Projection of Water Demand and Nutrient Emissi ons – The GLOWA-Elbe approach, Poster presented at the Statuskonferenz Glowa-Elbe II, Köln May 18-19, 2005, www.glowa-elbe.de/ pdf/status_mai2005/04poster-tub.pdf.

Helming, Katharina; Pérez-Soba, Marta; Tabbush, Paul. *Sustainability Impact Assessment of Land-use Changes. Springer,* (Eds.) 2008, X, 508 p. 72

Hersperger,A.M. and Bürgi, M. (2007) Driving forces of landscape change in the urbanizing Limmat valley, Switzerland. Chapter 3 in: Koomen, E., Stillwell, J., Bakema, A. and Scholten, H. (Eds.), *Modelling land-use change; progress and applications*, Springer, Dordrecht, pp. 45-60. http://reports.eea.europa.eu/eea_report_2006_11/en

Kalnay E. and Cai M. (2002) *Impact of urbanization and land-use change on climate.* Nature 423, 528-531.

Koomen, E. (2008) Spatial analysis in support of physical planning, Ph.D thesis, Vrije Universiteit.

Koomen, E., Rietveld, P. and De Nijs, T. (2008a) Modelling land-use change for spatial planning support, *Annals of Regional Science* 42 (1): 1-10.

Koomen, E., Loonen, W. and Hilferink, M. (2008b) Climate-change adaptations in land-use planning; a scenario-based approach. Lecture Notes on Geo-Information, Springer, Dordrecht (forthcoming).

Lambin, E.F., Geist, H.J. and Lepers, E. (2003) Dynamics of land-use and land-cover change in tropical regions, *Annual Review of Environment and Resources* 28: 205-241

Lambin, E.F., Turner, B.L., Geist, H.J., Agbola, S.B., Angelsen, A., Bruce, J.W., Coomes, O.T., Dirzo, R., Fischer, G., Folke, C., George, P.S., Homewood, K., Imbernon, J., Leemans, R., Li, X., Moran, E.F., Mortimore, M., Ramakrishnan, P.S., Richards, J.F., Skanes, H., Stone, G.D., Svedin, U., Veldkamp, T.A., Vogel, C. and Xu, J. (2001) The causes of land-use and land-cover change, moving beyond the myths, Global Environmental Change, 11: 261-269.

Lavalle C., Barredo J. I., McCormick N., Engelen G., White R., Uljee I. (2004) *The MOLAND model for urban and regional growth forecast: A tool for the definition of sustainable development paths*. DG-JRC, Ispra, EUR 21480 EN.

Loonen, W., Heuberger, P. and Kuijpers-Linde, M. (2007) Spatial optimisation in land-use allocation problems. Chapter 9 in Koomen, E., Stillwell, J., Bakema, A. and Scholten, H.J. (eds.) *Modelling land-use change; progress and applications*, Springer, Dordrecht, pp. 147-165.

MNP (2006) (Edited by A.F. Bouwman, T. Kram and K. Klein Goldewijk), Integrated modelling of global environmental change. An overview of IMAGE 2.4. Netherlands Environmental Assessment Agency (MNP), Bilthoven, The Netherlands.

MNP (2007) Nederland Later; Tweede Duurzaamheidsverkenning deel fysieke leefomgeving Nederland. MNP-publicatienr.500127001/2007. Milieu- en Natuurplanbureau, Bilthoven.

NERI (2004) *SENSOR indicator framework, and methods for aggregation/dis-aggregation – a guideline. 157 pp. Available at: http://www.sensor-ip.org/*

Ritsema van Eck, J. and Koomen, E. (2008) Characterising urban concentration and land-use diversity in simulations of future land use. Annals of Regional Science 42(1): 123-140.

Pontius Jr., R.G., Boersma, W.T., Castella, J-C., Clarke, K., De Nijs, T., Dietzel, C., Duan, Z., Fotsing, E., Goldstein, N., Kok, K., Koomen, E., Lippitt, C.D., McConnell, W., Pijanowski, B.C., Pithadia, S., Sood, A.M., Sweeney, S., Trung, T.N., Veldkamp, A. and Verburg, P.H., (2008) Comparing the input, output, and validation maps for several models of land change, Annals of Regional Science 42 (1): 11-37.

Scholten, H.J., Van de Velde, R., Rietveld, P. and Hilferink, M. (1999) Spatial information infrastructure for scenario planning: the development of a land-use planner for Holland, in Stillwell, J., Geertman, S. and Openshaw, S. (eds.) Geographical Information and Planning, Springer-Verlag, Berlin, pp. 112-134.

Schotten, C.G.J., Goetgeluk, R., Hilferink, M. Rietveld, P. and Scholten, H.J. (2001a) Residential construction, land-use and the environment. Simulations for the Netherlands using a GIS-based land-use model, Environmental Modeling and Assessment, 6: 133-143.

Schotten, C.G.J., Heunks, C., Wagtendonk, A.J., Buurman, J.J.G., De Zeeuw, C.J., Kramer, H. and Boersma, W.T. (2001b) Simulating Europe in the 21th century. NRSP-2 report 00-22, BCRS, Delft.

Schulp, C.J.E., Nabuurs, G.J. and Verburg, P.H. (2008) Future carbon sequestration in Europe--Effects of land use change. Agriculture, Ecosystems & Environment 127(3-4): 251-264.

Sheridan, P., Schroers, J.O. and Rommelfanger, E. (2007) GIS-based modelling of land-use systems; EU Common Agricultural Policy reform and its impact on agricultural land-use and plant species richness. Chapter 21 in Koomen, E., Stillwell, J., Bakema, A. and Scholten, H.J. (eds.) *Modelling land-use change; progress and applications*, Springer, Dordrecht, pp. 375-389.

Timmermans, H., Batty, M., Couclelis, H., Wegener, M. (2007) *Scientific audit of national land-use models; report and recommendations of the audit committee*, Netherlands Environmental Assessment Agency (MNP), Bilthoven.

Turner, B.L., Moss, R.H. and Skole, D.L. (1993) *Relating land-use and global land-cover change: A proposal for an IGBP-HDP core project*. Report from the IGBP-HDP Working Group on Land-Use/Land-Cover Change. Joint publication of the International Geosphere-Biosphere Programme (Report No. 24) and the Human Dimensions of Global Environmental Change Programme (Report No. 5). Stockholm: Royal Swedish Academy of Sciences.

UNECE and FAO (2005) *European Forest Sector Outlook Study 1960-2000-2020, Main Report*. ECE/TIM/SP/20. Geneva, 265 pp. Available at: http://www.unece.org/trade/timber/docs/sp/sp-20.pdf

Van Delden H., Luja P. and Engelen G. (2005) *Integration of multi-scale dynamic spatial models of socio-economic and physical processes for river basin management.* Environmental Modelling & Software 22, pp. 223-238.

Van der Hoeven, N., Aerts, J., Van der Klis, H. and Koomen, E. (2008) An Integrated Discussion Support System for New Dutch Flood Risk Management Strategies. Chapter 8 in: Geertman, S. and Stillwell, J. (eds.) Planning Support Systems: Best Practices and New Methods, Springer, Berlin (forthcoming).

Van Ittersum, M.K., Ewert, F., Heckelei, T., Wery, J., Olsson, J.A., Andersen, E., Bezlepkina, I., Brouwer, F., Donatelli, M., Flichman, G., Olsson, L., Rizzoli, A.E., Van der Wal, T., Wien, J.E. and Wolf, J. (2008) Integrated assessment of agricultural systems - A component-based framework for the European Union (SEAMLESS). Agricultural Systems 96(1-3): 150-165.

Verburg, P.H., Schot, P.P. Dijst, M.J. and Veldkamp, A. (2004) Land-use change modelling: current practice and research priorities, GeoJournal 61: 309-324.

Verburg, P.H.; Kok, K.; Pontius Jr., R.G.; Veldkamp, A. (2006) Modelling Land-Use and Land-Cover Change. In: Lambin, E.F., Geist, H.J. (eds.) Land-Use and Land-Cover Change. Local Processes and Global Impacts, Springer, Dordrecht, (Global Change - The IGBP Series), pp. 117 - 135.

Verburg, P.H. and Overmars, K.P. (2007) Dynamic simulation of land-use change trajectories with the CLUE-s model. Chapter 18 in: Koomen, E., Stillwell, J., Bakema, A. and Scholten, H.J. (eds.) Modelling land-use change; progress and applications, Springer, Dordrecht, pp. 321-335.

Verburg, P.H. , Eickhout B and van Meijl H. (2008) A multi-scale, multi model approaches for analysing the future dynamics of European land-use. Annals of Regional Science 42(1): 57-77.

Watson, R.T., Noble, I.R., Bolin, B., Ravindranath, N.H., Verardo, D.J. and Dokken, D.J. (eds) (2000) *Land-use, Land-Use Change, and Forestry: A Special Report of the Intergovernmental Panel on Climatic Change*, Cambridge University Press, Cambridge.

White, R. and Engelen, G. (2000) High-resolution integrated modelling of the spatial dynamics of urban and regional systems. Computers, Environment and Urban Systems 24 (2000): 383-400.

The appendices are included in a separate document.